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EMC AEROSPACE SYSTEMS ANALYSIS

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FOREWORD

This report was prepared for the Microwave Laboratory of the NASA Electronic Research Center, Cambridge, Massachusetts by the Systems Sciences Research Division of the IIT Research Institute (IITRI) under Contract Number NAS-12-639. The report was prepared under the technical direction of Mr. John M. Clarke of NASA/ERC, by Mr. Richard J. Otero and Mr. William C. Wanbaugh of IITRI. Other personnel of the IIT Research Institute who contributed to this report were:

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LIST OF ABBREVIATIONS

ATA	Air Transport Association of America
ATC	Air Traffic Control
CAS	Collision Avoidance System
CCIR	International Radio Consultive Committee
DOD	Department of Defense
ECAC	Electromagnetic Compatibility Analysis Center
EMC	Electromagnetic Compatibility
EMETF	Electromagnetic Environmental Test Facility
EMI	Electromagnetic Interference
ESD	Electronic Systems Division
FAA	Federal Aviation Agency
FCC	Federal Communications Commission
GEESE	General Electric Electronic System Evaluation
IRAC	Interdepartment Radio Advisory Committee
IPP	Interference Prediction Process
ITU	International Telecommunication Union
JTAC	Joint Technical Advisory Committee
MSS	Master System Simulator
ODTM	Office of the Director of Telecommunication Management
RF	Radio Frequency
SST	Super-Sonic Transport
TIPPS	Technically Improved Interference Processing System
V/STOL	Vertical-Short Take-Off and Landing
V/TOL	Vertical Take-Off and Landing

LIST OF SYMBOLS

T_s	Synchronization time for CAS
S/I	Signal to interference ratio
S/N	Signal to noise ratio
I/N	Interfering signal to noise ratio
G_t	Interference transmitter antenna gain
G_r	Victim receiver antenna gain
d	Distance between interference transmitter and receiver
R_s	Receiver sensitivity
H	Width chosen for integration strip
W_m	Transmitter power spectral density in the m^{th} integration strip
H_m	Receiver selectivity relative to sensitivity in the m^{th} integration strip
ψ	Angular displacement between antennas on SST
P_D	Spatial power density at the location of the victim receiver
P_T	Transmitter power of the potential interference emitter
A_e	Effective aperature of the transmitting antenna
L	Propagation path loss between transmitter and receiver
$P_T(f+\Delta f)$	Power spectral density of the interfering transmitter
$\lvert H(f)\rvert^2$	Selectivity function of the victim receiver
N_R	Receiver noise power
P	Interference margin, or the amount by which the interference power exceeds the minimum power required to produce interference in the receiver

LIST OF SYMBOLS (Continued)

P_R	Minimum power required to produce interference in the receiver
$P(nf_o)$	Mean power at the n^{th} harmonic of the fundamental frequency
n	Harmonic number
A,B	Constants determined from the statistical analysis for transmitters or tranamitter classes
P_{nm}	Intermodulation output power
n,m	Integers
p	An integer representing the harmonic order of the local oscillator
q	An integer representing the harmonic order of the interference signal

1.0 SUMMARY

EXAMINATION, COMPARISON AND RECOMMENDATIONS

A description of the program objectives, the major findings of the study and a brief summary of the contents of the report are included here.

This interim scientific report presents the results of a study conducted for the Microwave Laboratory of the NASA Electronic Research Center, Cambridge, Massachusetts. The objective of this study was basically to examine potential aerospace electromagnetic compatibility (EMC) problems, determine the analysis and data requirements necessary for solving these problems, compare these requirements against the availability of analytical tools and data bases and finally to make recommendations for research and capability development programs designed to overcome these limitations and voids.

During the first stage of the study, several systems proposed for the 1540 to 1660 MHz aeronautical radio navigation segment of L-band were examined to determine what are the aerospace EMC analysis and data requirements. Both cosite and far-field interfering situations were considered and each of the required analytical capabilities used as well as those not used because they were not developed as yet, not directly applicable or not available to NASA, are discussed in later sections. A specific recommendation, formulated during this stage of the study, concerning a required 20 MHz frequency separation between the collision avoidance system and the air traffic control (L-band via satellite) system, for interference free operation is discussed in Section 3.1.2 entitled, An Examination of the L-Band Aerospace Compatibility Problem.

Section 3.2 includes a summary of the existing EMC analysis, measured, environmental and equipment characteristics data capabilities. Also included within this section is the rationale for the conclusion that there is a lack of direct applicability of available electromagnetic compatibility analysis techniques to those peculiar RFI problems encountered with satellite and high performance aircraft such as the SST.

Section 3.3, NASA EMC Analysis Requirements, describes four capability programs that should be developed immediately to make possible the successful solution of a majority of EMC aerospace problems. The programs described are in the area of aerospace receiver modelling, space channel characterization, an automated interference analysis tool and a cosite model for satellites and aircraft.

Section 3.4, NASA EMC Measured Data Requirements, describes a research program for determining the feasibility of obtaining meaningful man-made radio frequency noise at orbital altitudes.

Section 3.5, NASA EMC Environmental and Equipment Characteristics Data Requirement, spells out the categories of data and their physical format required for the solution of aerospace EMC problems. Procedures for obtaining the required data are also presented in this section.

Section 3.6, presents the data processing requirements and availability for use in developing a NASA EMC analysis capability. The use of computers for EMC file storage, sorting and retrieval and for the computations involved in an interference situation are explored. In addition to digital computer use for EMC analysis purposes, the use of analog and hybrid processors is also discussed.

Section 3.7, Three Additional Elements in Developing a NASA EMC/Frequency Management Capability, discusses programs for the improvement of existing EMC standards and specifications, EMC information dissemination, education, and analysis and design guidance via a series of handbooks, and a frequency management program responsive to current NASA EMC problems and capable of projecting and providing for NASA frequency requirements in the 1970's.

2.0 INTRODUCTION

A NASA ELECTROMAGNETIC COMPATIBILITY RESEARCH PROGRAM

The complexity, cost and critical bearing on the national interest of the NASA space programs precludes the use of yesterday's build it, measure it, fix it approach in dealing with today's spacecraft and aerospace equipment RFI problems.

A major cost in implementing any space program is that of vehicle launch. These launch costs, coupled with the inaccessibility of aerospace equipments for modification once launched, makes critical the identification and elimination of potential interference problems. These problems, a possible source of mission failure, must be identified early in the definition phase of a system's development and especially prior to the allocation of a frequency band or assignment of operating frequencies to the system. An electromagnetic compatibility program implemented at the system definition phase can eliminate potential co-channel, adjacent channel and harmonic interference problems and alert the system designer to the possibility of serious spurious response, intermodulation, crossmodulation, desensitization and high power effect problems before they materialize.

This report, prepared for the Electromagnetic Systems Branch, Microwave Laboratory of the Electronics Research Center of NASA summarizes the result of a program designed to (1) determine the electromagnetic compatibility (EMC) analysis capabilities required by NASA, (2) identify the additional research requirements in this area, (3) develop a plan for the implementation of a NASA EMC/Frequency Management Capability, (4) identify the measured, environmental and equipment data needs of NASA, (5) make recommendations in the area of computer and data-processing for EMC problem analysis, and (6) investigate the feasibility of establishing a NASA/ERC problem analysis service.

3.0 EMC AEROSPACE SYSTEMS ANALYSIS

3.1 The EMC Analysis Capability Required by NASA

3.1.1 An Introduction to EMC for Aerospace Problems

AEROSPACE SYSTEMS INVOLVE ALL TYPES OF COMPATIBILITY SITUATIONS

The object of identifying the electromagnetic compatibility problems which could occur in aerospace situations is treated by examining the new equipments proposed for use in the aeronautical radionavigation portion of L-band.

The objective of this preliminary six month study is to identify and categorize the major aerospace EMC analysis problems. During the proposal phase of this contract discussions were held with NASA/ERC representatives and it was agreed that the major emphasis during the study should be placed on L-band equipments which are now being considered for Satellite Air Traffic Control (ATC), Navigation, and a Collision Avoidance System (CAS). Although the primary objective must remain the identification of problems associated with analyzing electromagnetic compatibility situations, recommendations will be made to the extent possible for each of the systems investigated. The L-band aerospace systems involve all of the compatibility situations which one might expect to encounter in frequency management problems for future aerospace systems. The variety of problem types will become obvious in the following discussion of the L-band systems considered.

3.1.2 An Examination of the L-band Aerospace Compatibility Problem

A SAMPLE PROBLEM POINTS TO CAPABILITY LIMITATIONS

An examination of the potential incompatibility between the satellite air traffic control navigation systems and collision avoidance systems proposed to operate on the Supersonic Transport within the same frequency band, provided the vehicle for categorizing typical aerospace EMC problems and for identifying major analysis capability limitations and voids in this area.

The L-band (1540-1660 MHz) systems which have been used for the sample problem are, (1) a Communications/Navigation Satellite System and (2) a Collision Avoidance System. The satellite system could provide air traffic control communication links as well as navigation data to the Supersonic Transports (SST's) of the 1970's. The links include aircraft-to-satellite and satellite-to-ground in both directions. The L-band Collision Avoidance System has been described by the Air Navigation/Traffic Control Division of the Air Transport Association of America (ATA). In this system a one-way transmission only is required for the CAS function with range and range rate measurement possible by virtue of the accurate time and frequency maintained by all participants. The transmitted message consists of both a pulse position code and a bi-phase modulation of a 200 μs pulse.

Study of the L-band systems includes the co-located equipment problem such as the satellite ATC communication system being located aboard the supersonic transport which also will be carrying a collision avoidance system transmitter and receiver. This particular cosite problem is of great interest to all those concerned with compatible systems operation in the 1540 to 1660 MHz frequency range. In addition to the cosite problem, the far field analysis for compatibility involves the supersonic aircraft, the communication/navigation satellite, other aircraft, and L-band terrestrial facilities. Therefore, a large environment of equipments must be considered because of the large area of the earth's surface viewed from the altitude of a synchronous satellite. An SST flying at 80,000 feet will have a radio line-of-sight of 714 nautical miles which means that emitters and receivers in an area exceeding a million and a half square miles should be considered for compatibility purposes.

Present day ATC is handled at VHF frequencies which is adequate for line-of-sight communications. The supersonic aircraft will be beyond line-of-sight of the airport within twelve minutes of take-off time. The satellite relay can extend the radio contract between the aircraft and any point necessary to 100 percent coverage. Several system considerations indicate that the presently assigned aircraft, HF, VHF and low UHF frequencies are undesirable for the satellite relay application. Tests at VHF frequencies have shown high corona noise in bad weather, signal polarization shifting and multipath reception from sea water reflections (1). Operation at upper UHF band (L-band) will permit use of allocated space communication spectrum; near optimum transmission efficiency; wide bandwidth operation; and small, lightweight, high gain vehicle antennas. The use of HF for long distance transmission permits extremely low data rates of less than 150 bits/second because of the poor quality of the transmission media. Short range VHF/UHF ground to air line-of-sight links permit moderate to high data rates up to 1200 bits/second with acceptable error rates (2).

The proposed CAS is based on a timed transmission arrangement where each aircraft transmits in turn while all others listen. It is essential that each plane receive the data necessary to prevent an impending collision. The CAS message is made up of information including range, range rate, altitude, and altitude rate. The system is based on very precise time synchronization between all of the cooperating aircraft. Each aircraft transmits a signal in a unique message slot at an exact predetermined time. This transmission time is known in each aircraft so that the delay between transmission time and pulse arrival time can be used to make a direct measurement of the range to the transmitting aircraft. The long 200 microsecond pulse permits the measurement of relative frequency shift between the transmitting and receiving aircraft. In order to accomplish the measurement, the carrier frequency of all of the cooperating aircraft must be in agreement. The length of the range/range rate pulse is determined by the relative velocity accuracy requirement and has been chosen as a compromise between power, accuracy, and concise message format.

An important parameter in the ATA CAS is the quantity range divided by range rate. This quantity designated "tau" is an exact measurement of time to nearest approach for aircraft which are on linear collision courses. Warning envelopes are based on time to nearest approach for fast closing aircraft or on minimum range for aircraft which are not closing rapidly but are fairly close. The CAS affords protection from accelerating aircraft due to the fact that the information is updated once every three seconds.

Additional information which is available aboard any aircraft can be telemetered via the CAS signal format to another aircraft. The parameter, pressure altitude, is required to be communicated in the ATA system. This information is used to determine whether an altitude maneuver is required in order to provide safe separation from an intruding airplane.

If an intruding airplane is found to be a threat because of either range or tau falling below the minimum allowable values and is also co-altitude, an altitude maneuver command is displayed in the cockpit. An up or down indication is given depending on the measured difference between altitudes. In order to positively prevent the same maneuver command occurring in both aircraft, the telemetered altitude is biased in the direction of the maneuver command by approximately 200 feet to force an opposite maneuver on the other aircraft.

Figure 1 shows the basic minimum message format that is required to be transmitted by all aircraft. The range/range rate pulse is transmitted at exactly 15 microseconds after the beginning of the message slot. The time of arrival of the leading edge of this pulse is used to determine the range to the transmitting system. The shift in frequency as used from the coherent RF carrier in the 200 microsecond pulse is used to evaluate the closing rate of the transmitting aircraft. The altitude information is transmitted as a 4 microsecond position coded pulse with zero altitude at 720 mircoseconds after the leading edge of the range/range rate pulse. This pulse is moved one microsecond earlier for each 250 feet of altitude above sea level. It is anticipated that a maximum of 80,000 feet will be accommodated which leaves a multipath guard band of 200 microseconds to insure that the altitude pulse will be free from multipath effects. Synchronization pulse returns from the master station will be received at the end of the message slot at time T_s if the aircraft is correctly synchronized. This synchronization time, T_s, occurs 80.8 microseconds ahead of the end of the message slot and consists of a three-pulse signal; each pulse is 1.6 microseconds in duration with a recognizably different code for ground master and air master sync replies.

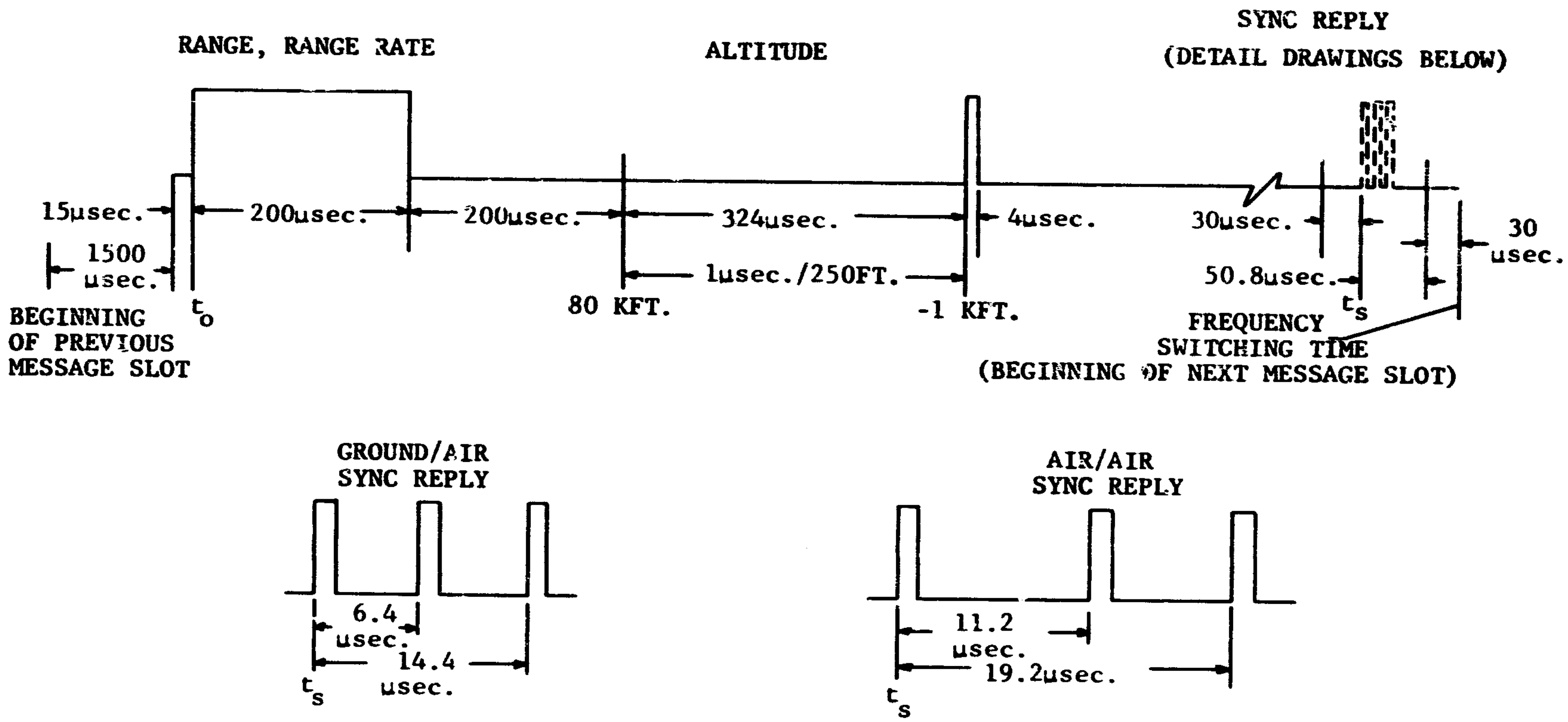


FIGURE 1

COLLISION AVOIDANCE SYSTEM MESSAGE FORMAT, BASIC SIGNAL

The format of Figure 2 is the total ATA format including the options and/or growth items of altitude rate and velocity vector. In addition, the 200 microsecond range/range rate pulse will be modulated in fully equipped aircraft to transmit information required for the propagation of time hierarchy information consisting of time hierarchy, sync requests and identity. The modulation will be in the form of a bi-polar phase shift where the frequency of the signal is held constant but the phase is shifted 180 degrees from one pulse to the next to indicate a "1" and no phase shift is used to indicate a "0". The use of this form of modulation allows transmission of digitally coded data while preserving the frequency coherence of the signal so that it can be used for doppler frequency shift measurements. The bi-phase characteristic of the signal is removed in the receiving circuit by multiplying by two and filtering. Altitude rate is provided for in the complete format as a pulse position coded signal as shown in Figure 2. The total excursion of ± 20 microseconds corresponds to a maximum climb/dive rate of 10,000 feet per minute. This high rate was chosen to include all present and planned civil aircraft. The signals which have been pulse position coded for the proposed Collision Avoidance System are those which must be received without garbling. Other information which was considered of less significance or which does not have to be received in any single transmission has been included in the bi-phase modulation of the range rate pulse.

An interference problem area on-board the supersonic transport is the possible interaction of the CAS and the air traffic control system. Both systems are designed to operate in the 1540 to 1660 MHz band and the message format of the CAS has been studied to arrive at a spectrum emission model. The most pessimistic approach or widest spectrum results from

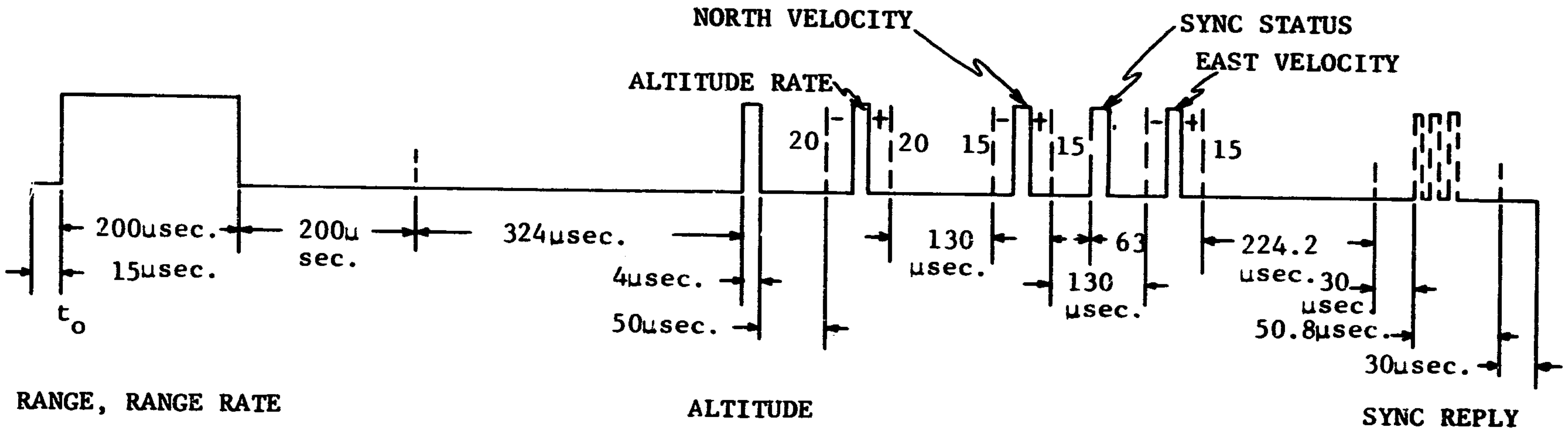


FIGURE 2

COLLISION AVOIDANCE SYSTEM MESSAGE FORMAT, GROWTH & OPTIONAL DATA synthesizing an emission spectrum based on the bi-phase modulation used to convey identity, sync requests and time hierarchy. A bit representing a "1" or a "0" is two microseconds in duration with a phase shift of 180° occurring in the middle. The bit is determined to be a "1" or a "0" by comparing phase with the previous bit. A phase shift between bits denotes a "1" and no phase change between bits denotes a "0". A series of ones will create the widest emission spectrum due to a 180° phase shift every microsecond. Although the bi-phase modulation is contained within a 200 microsecond pulse the spectrum width will be determined by the narrowest component which in the worst case will be a series of one microsecond pulses. However, even the transmission of a series of zeros where no phase shift occurs between bits will result in a spectrum based on a two microsecond pulse, due to the 180° phase shift which occurs in the middle of each bit. The CAS emission model used for the NASA L-band study is included in the following description of the analysis for cosite interference from the CAS transmitter into the air traffic control receiver on the supersonic transport.

The proposed CAS and ATC systems must both operate on the SST within the band of 1540 to 1660 MHz. Due to the proximity of the equipments they will not be able to share the same frequency. The interference analysis involves computing the interaction between the CAS transmitter emission model and the ATC receiver model for increments of frequency (Δf) for the off tuning.

The computer program solves the following expression:

$$S/I = S/N - I/N \tag{1}$$

where:

S/I = signal-to-interference ratio in dB
S/N = signal-to-noise ratio in dB

I/N = interfering signal-to-noise ratio in dB

Equation 1 is expanded to include all of the factors normally associated with a free space signal-to-interference ratio computation as follows:

$$S/I = S/N - G_T - G_R + 20 \log f + 20 \log d + 37 + R_s$$

$$-10 \log H \sum_{m=f_1}^{m=f_2} \log^{-1} \frac{W_m - H_m}{10}$$

where:

G_T = interference transmitter antenna gain in dB

G_R = victim receiver antenna gain in dB

f = frequency in center of frequency range considered in MHz

d = distance between interference transmitter and receiver in miles

R_s = receiver sensitivity in dBm

H = width chosen for a strip of integration in MHz

W_m = transmitter power spectral density in the m^{th} strip in dBm/MHz

H_m = receiver selec.ivity relative to sensitivity m^{th} strip in dB

The CAS transmitter to ATC receiver problem inputs to the distance versus frequency program are given below.

S/I = + 20 dB S/N = + 20 dB	requires interference signal to be at threshold of victim receiver
$G_T = G_R = 0$	the distance output of the program was adjusted based on the SST antenna coupling as explained later

f = 1600 MHz

R_s = -95 dBm for 1 MHz bandwidth (based on sensitivity of - 155 dBm/Hz.)

H = 0.5 MHz

W_m = given below (transmitter power spectral density)

Δf = 1.0 MHz (program computes a distance for an S/I = 20 dB every MHz)

CAS transmitter power spectral density "W" (Preliminary estimate)

f MHz	W dBm/MHz
0	50
1	50
25	15
50	-20
62	-22
75	-25
100	-30

ATC receiver selectivity "H" (Preliminary estimate)

f MHz	H dB
0	0
.5	0
1.0	15
1.75	60
10	80
50	110
100	150

The output of the frequency versus distance program is shown in Table 1.

TABLE 1

CAS TRANSMITTER VERSUS ATC RECEIVER FREQUENCY-DISTANCE SEPARATION DATA

($S/I = 20dB$, $G_r = G_t = 0dB$, FREE SPACE LOSS)

Frequency Separation MHz	Distance Separation Miles	Frequency Separation MHz	Distance Separation Miles
0	196	16	15.8
1	189	17	13.2
2	165	18	11.2
3	140	19	9.5
4	118	20	8.1
5	100	21	6.8
6	84.5	22	5.7
7	71.5	23	4.8
8	60.5	24	4.1
9	51.0	25	3.4
10	43.3	26	3.0
11	36.4	27	2.5
12	30.9	28	2.1
13	26.1	29	1.8
14	22.0	30	1.5
15	18.6		

Before the results shown in Table 1 can be adjusted for the cosite situation, the expected coupling between L-band antennas on a cylinder with a diameter of 14 feet representative of the SST configuration must be determined. The techniques developed for the Air Force Systems Command at Wright-Patterson Air Force Base by the University of Michigan (3) were used for this purpose. At the present time no firm information exists on the exact locations for the CAS and ATC antennas aboard the SST. The CAS will use two low gain antennas (3 dB), one mounted on the top of the aircraft and one on the bottom, near the forward portion of the SST. The CAS message transmission will be switched between these two antennas. The ATC antenna will probably be located on the topside near the aft end of the aircraft. It is expected to have a gain on the order of 12 dB. Figure 3 shows the SST with the distance between the CAS and ATC antennas selected for the purposes of this study as 135 feet. The actual separation probably will be in excess of 135 feet and the calculated answer will be slightly pessimistic.

The coupling between two antennas at a given frequency is defined as the ratio of the power received to the power transmitted. The major emphasis in Reference 3 is on the coupling between pairs of antennas mounted in a common conducting surface, as the skin of an airplane or missile, or a mounting plate. The nomographs given in the report are frequency sensitive in terms of using the number of wavelengths for distance between antennas, the radius of a cylinder representing an airframe, etc. A wavelength at 1570 MHz is 0.625 feet and the following equivalents are useful for the SST problem solutions.

	Feet	Wavelengths at 1570 MHz
SST radius	7	11.2

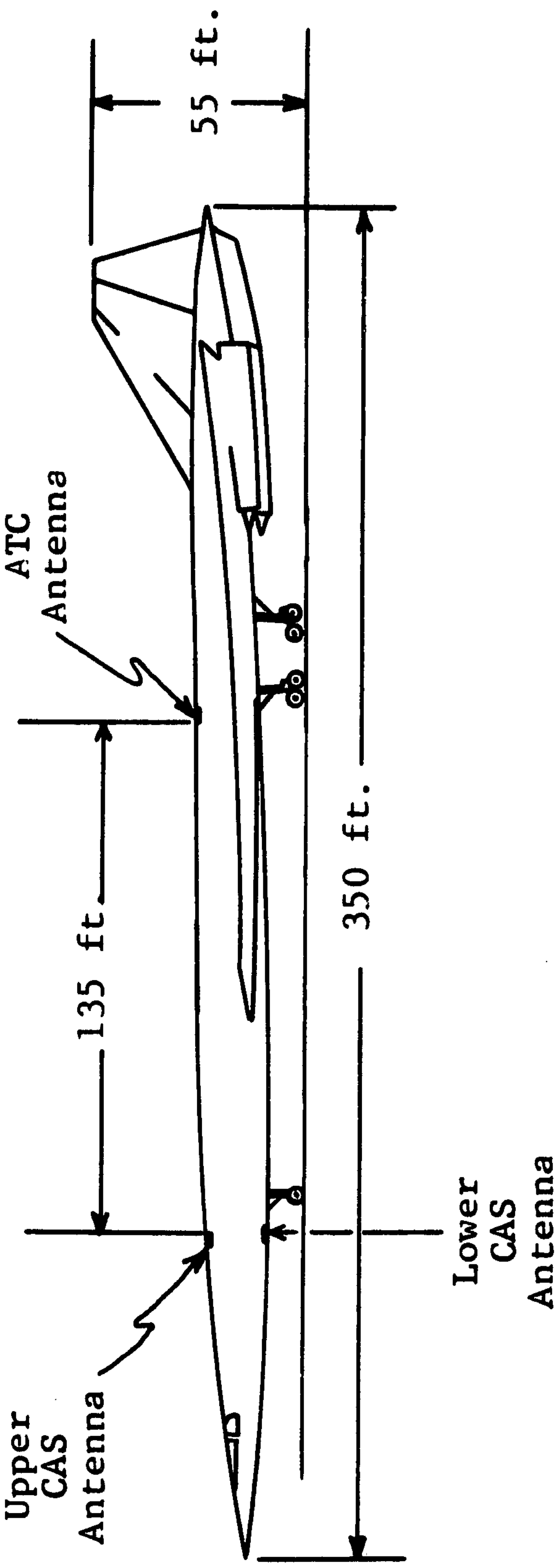


FIGURE 3. ASSUMED SST ANTENNA LOCATIONS

Distance between antennas	10	16
" " "	20	32
" " "	50	80
" " "	100	160
" " "	200	320

Figure 4 is a nomograph for determining the coupling between two quarter wave monopole antennas. For example, assume two antennas spaced 10 feet apart which at 1570 MHz is equivalent to a separation of 16 wavelengths. The coupling is found to be -41.7 dB. The data are based on quarter wave monopoles mounted flush on a conducting surface. For antennas with higher gains the coupling will be even less as long as main beam to main beam coupling is avoided which is a reasonable assumption for the SST. Table 2 indicates that the coupling between two quarter wave monopoles is greater than that for any other combination and especially higher than that for medium gain sectoral horns.

Figure 5 shows the angular and distance measurements used to adjust the basic coupling of Figure 4 for those antennas which are mounted on a cylindrical surface and displaced around that surface by some angle ψ. The additional coupling loss is found by using Figures 6 and 7. For SST antennas 10 feet apart and located 90° from each other enter Figure 6 with the radius of the cylinder in wavelengths which is 11.2 for the SST and for antennas which are 10 feet apart draw line 1 between 11.2 for radius to 16 wavelengths for distance. The intersection of line 1 with the central axis forms a point for one end of line 2. The other end of line 2 is located at ψ = 90°. The point where line 2 intersects the y scale is the y factor which equals 17 for this example. Figure 7 is used to convert the y factor (17) to the dB value of antenna coupling, -28 dB caused by the shielding of

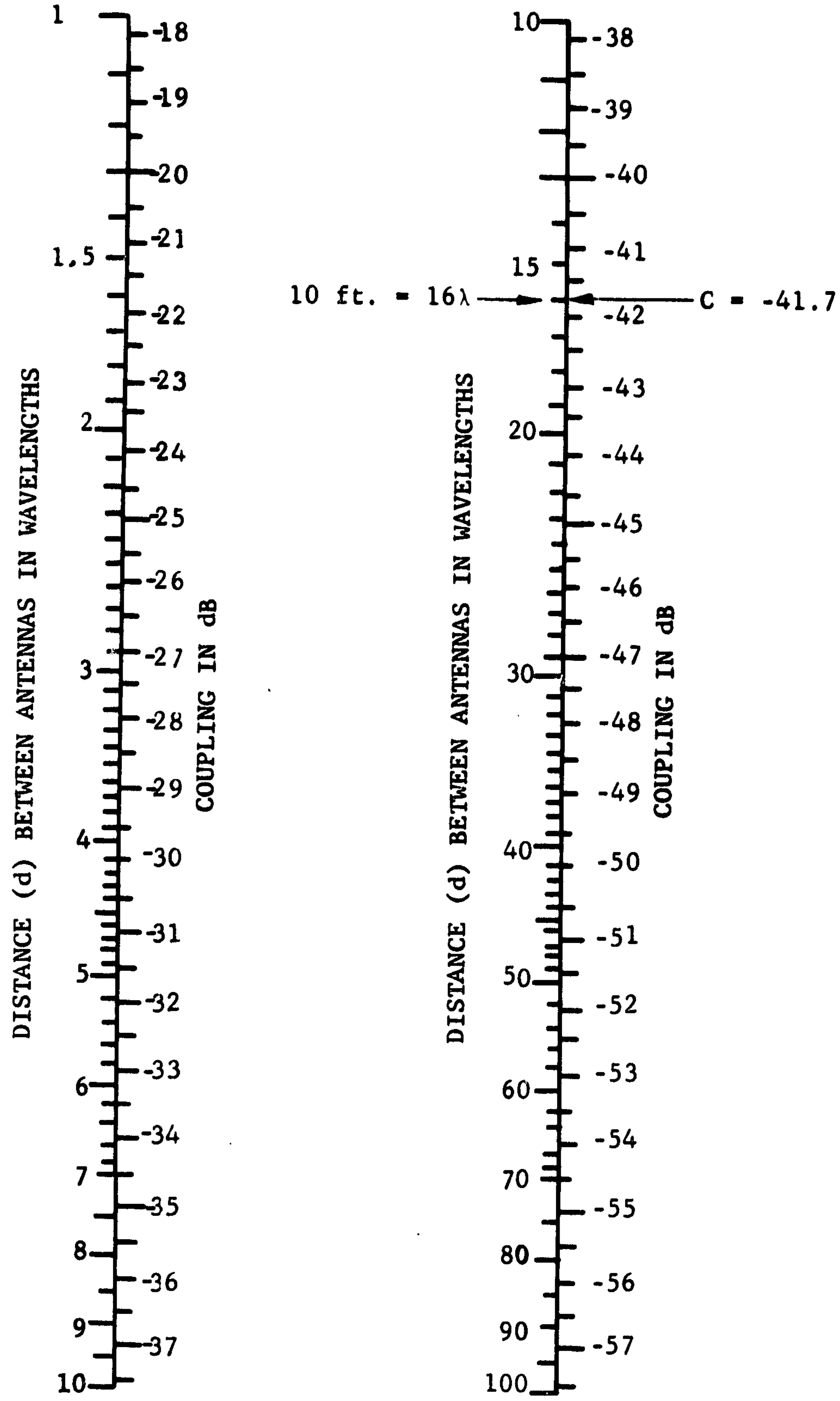


FIGURE 4

NOMOGRAPH FOR THE CALCULATION OF COUPLING BETWEEN TWO QUARTER WAVE MONOPOLE ANTENNAS

TABLE 2

COUPLING BETWEEN ANTENNAS AT ONE WAVELENGTH IN dB

Antenna Type	$\lambda/4$ monopole	Circular Spiral d = 10 cm	Rectangular Slot $a=0.8\lambda, b=0.4\lambda$	E-Sectoral $a=0.75\lambda, b=2.5\lambda$
$\lambda/4$ monopole	-17.7	-28	-17.8	-27
Circular Spiral	-28	-38	-28	-37
Rectangular Slot	-17.8	-28	-18	-27
E-Sectoral Horn	-27	-37	-27	-36

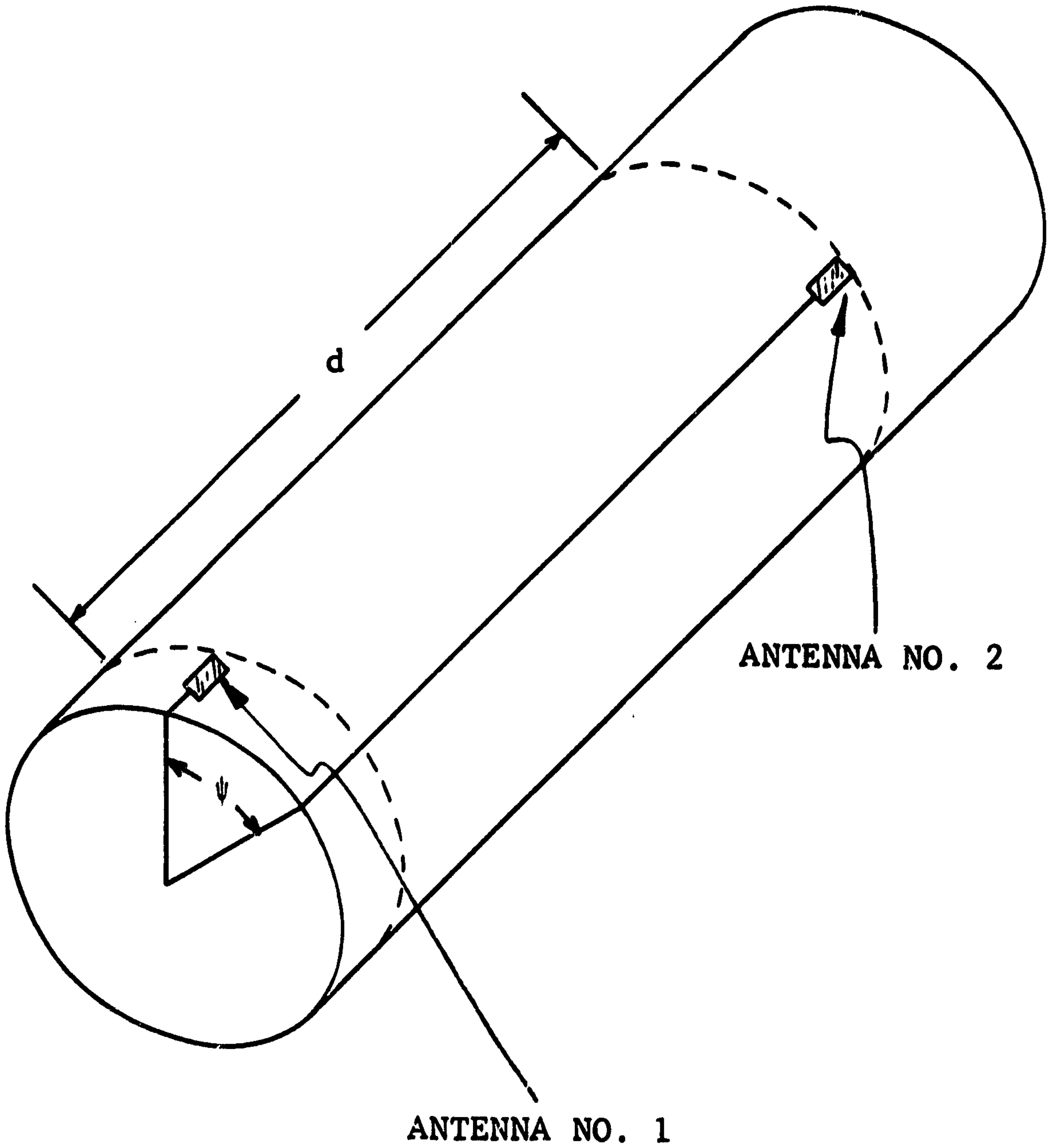


FIGURE 5

ANTENNA COORDINATES ON A CYLINDER

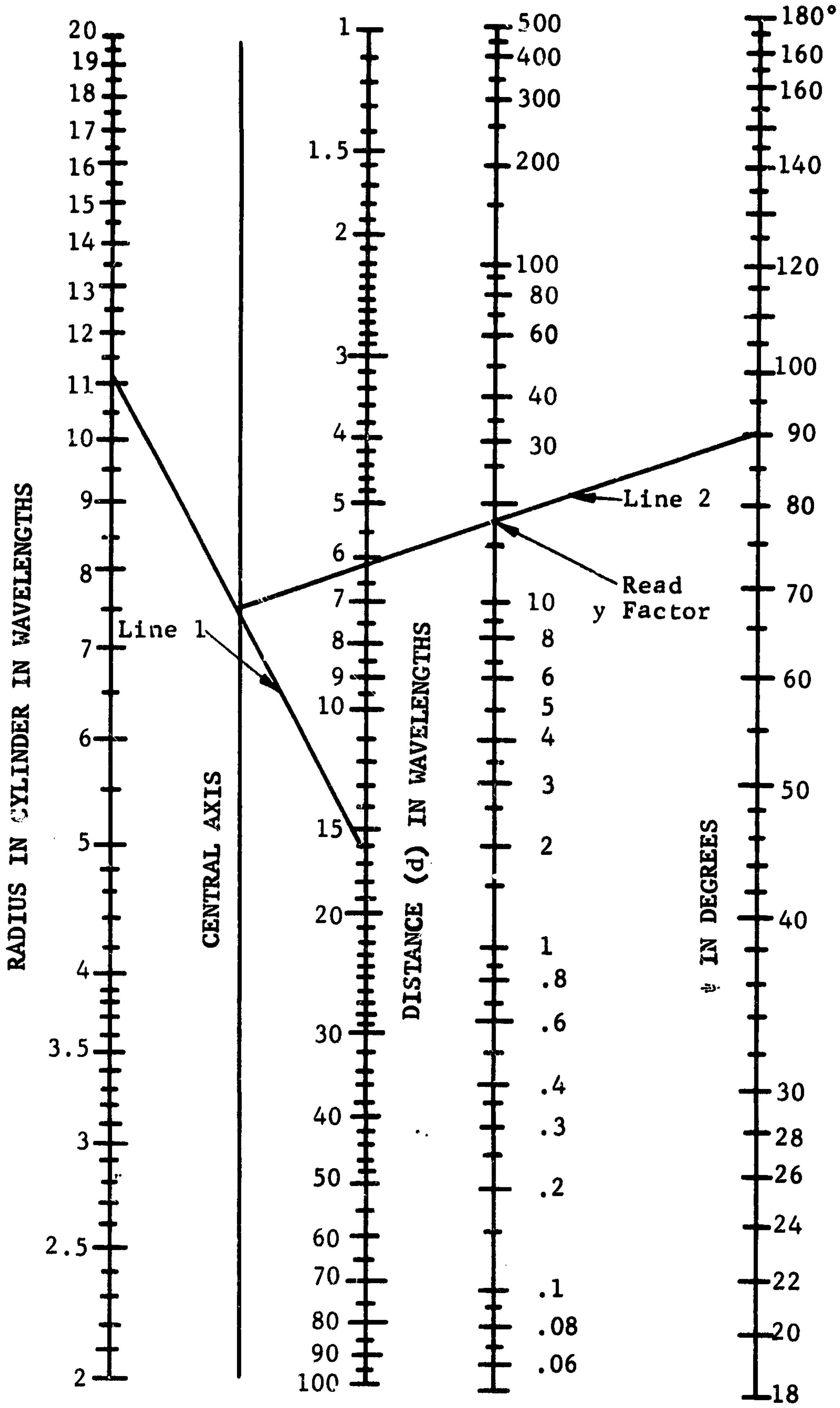


FIGURE 6

NOMOGRAPH FOR THE CALCULATION OF y FACTOR ON A CYLINDER

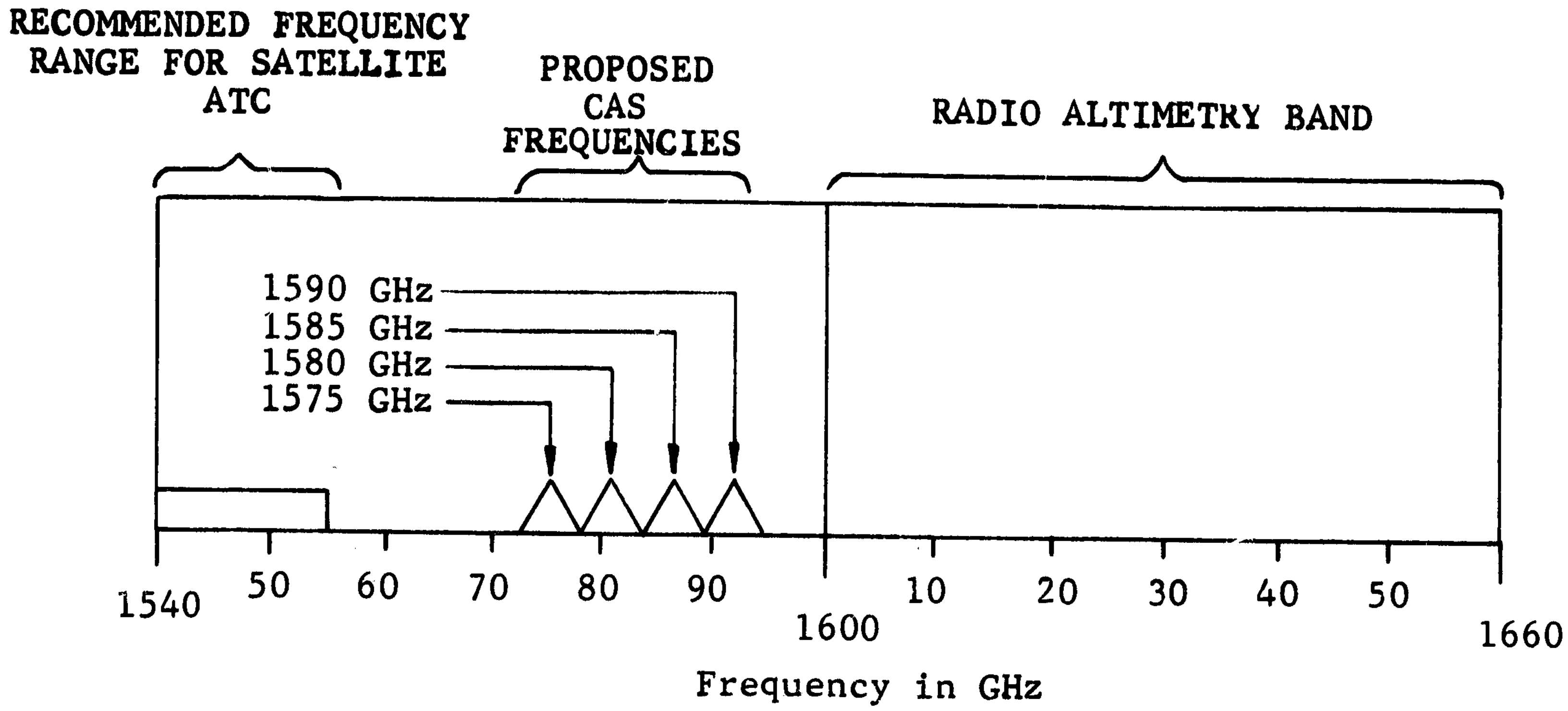


FIGURE 9

PROPOSED CAS AND RECOMMENDED ATC FREQUENCIES WITHIN THE 1540 TO 1660 GHz AERONAUTICAL RADIO NAVIGATION BAND the cylindrical shape. The additional loss due to the shielding of the cylinder and the angle between the two antennas is combined with the basic loss from Figure 4 to obtain a coupling of -69.7 dB. A family of curves for antenna coupling versus distance for various angles of ψ between 0° and 180° is generated in this manner. The family of curves for a 14 foot diameter SST is shown in Figure 8.

Returning now to the original problem of cosite interference between the CAS transmitter and the ATC receiver aboard the SST, the information just discussed will be used to analyze the problem. The following steps are presented to indicate the logical process used to evaluate the interference potential.

STEP	PROCEDURE	REFERENCE
1	Determine CAS to ATC antenna paths. One is 135 feet at ψ = 0°, the other is 135 feet at ψ = 180°.	Figure 3
2	Determine coupling between antennas at 135 feet and ψ = 0° (worst case). The coupling C is -64.2 dB.	Figure 8
3	Assume some reasonable Δf and determine d from computer program output. Assume Δf = 20 MHz and find d= 8.05 miles.	Table 1
4	Calculate the coupling at the selected Δf which will allow moving the antennas from a distance of 8.05 miles to a distance of 135 feet from each other. Use C' = -20 log 8.05 x 5280/135. Find C' = -49.8 dB	Calculate
5	Compare C to C'. Since C is -64.2 dB and a Δf of 20 MHz requires coupling of only 49.8 dB, a smaller Δf can be chosen without violating an S/I = + 20 dB.	Compare

6	Choose a new Δf and determine d from computer program output. Assume Δf = 10 MHz and find that d = 43.3 miles.	Table 1
7	Calculate the coupling loss at the selected Δf which will allow moving the antennas from a distance of 43.3 miles to a distance of 135 feet. Use $C' = -20 \log 43 \times 5280/135$ $C' = -64.5$ dB	Calculate
8	Compare C to C'. Find that C is about equal to C'. $-64.2 \approx -64.5$. It is concluded that at a distance of 135 feet on the skin of an airframe, 10 MHz is as close as the CAS and the ATC systems can be operated.	Conclusion

This conclusion is based on the largest coupling between the CAS and the ATC antennas and reference to Figure 8 shows that an additional 33 dB of loss exists for the path between the lower CAS antenna and the ATC antenna. The same figure shows that displacements up to $\psi = 45°$ afford little additional shielding over $\psi = 0°$, whereas $\psi = 90°$ through 180° provides 10 to 35 dB (at d = 100 feet).

The L-band ATC system is designed to operate via a synchronous navigation/communication satellite and the possibility of interference between the CAS transmitters on aircraft and the ATC receiver on a satellite 22,000 miles away has been examined. System data are not firm at the present time, but the following parameters are representative of the current thinking for an L-band ATC via satellite system and the L-band CAS system.

ATC L-Band Terminal Aboard SST

Antenna Gain	12 dB
Power Out	26 dBW
Radiated Power	38 dBW

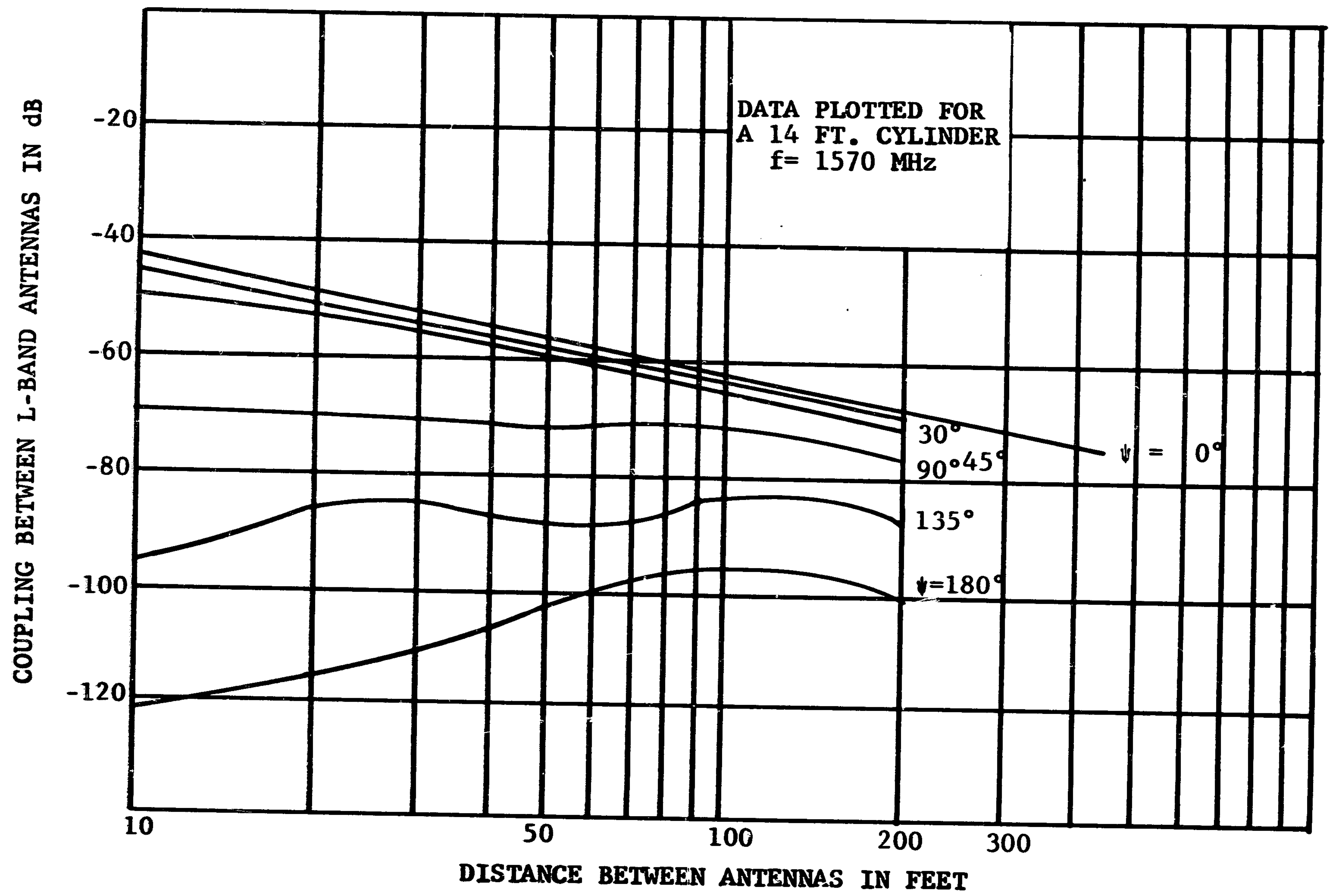


FIGURE 8

COUPLING BETWEEN ANTENNAS ON THE SST

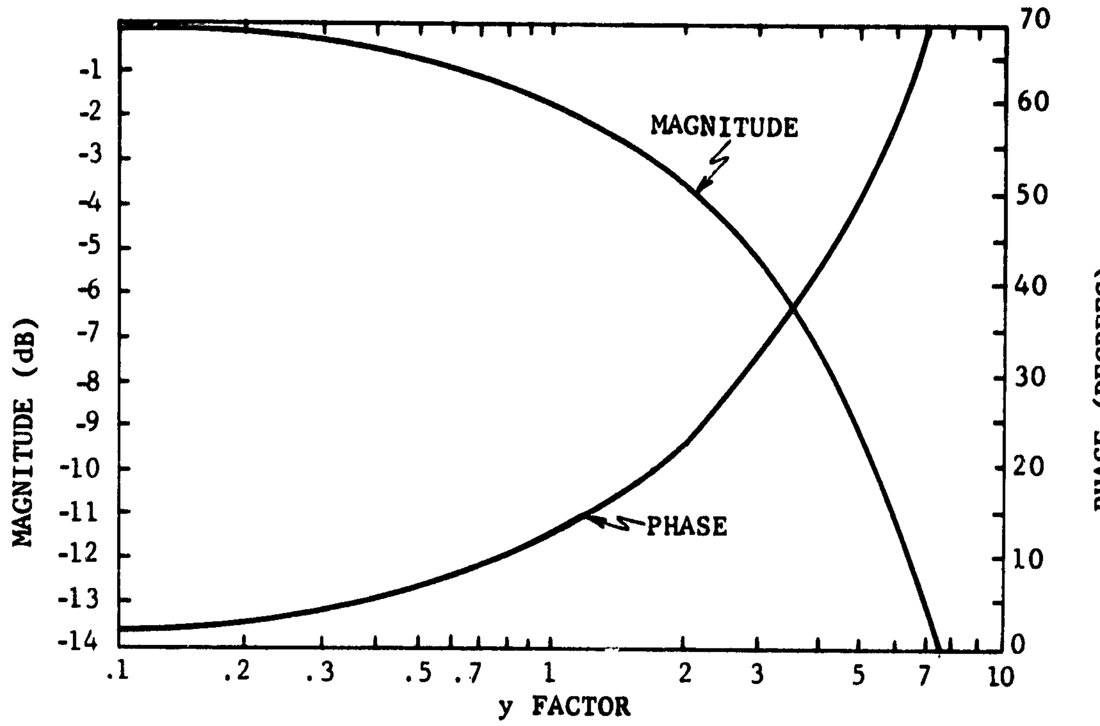
ATC L-Band Terminal on Satellite		
	Antenna Gain	23 dB
	Power Out	17 dBW
	Radiated Power	40 dBW
CAS Transmitter		
	Antenna Gain	3 dB
	Power Out	30 dBW
	Radiated Power	33 dBW

The CAS transmitters and ATC transmitters aboard aircraft will always be the same distance from a synchronous orbit satellite ATC receiver and the aircraft ATC effective radiated power is 5 dB greater than the CAS effective radiated power. An additional advantage for the ATC link is the isolation provided by the expected minimum frequency off-tuning of 10 MHz. This frequency separation will ensure that the narrow band phase lock loop receiver will see the CAS emission spectrum at a point at least 25 dB down from the peak power. The ATC receiver on the satellite will therefore be looking at a desired signal to interfering signal ratio (S/I) of at least +30 dB for a 10 MHz frequency separation. It can, therefore, be assumed that up to this point in the analysis a frequency separation between the CAS and ATC equipments of 10 MHz minimum will ensure interference free operation.

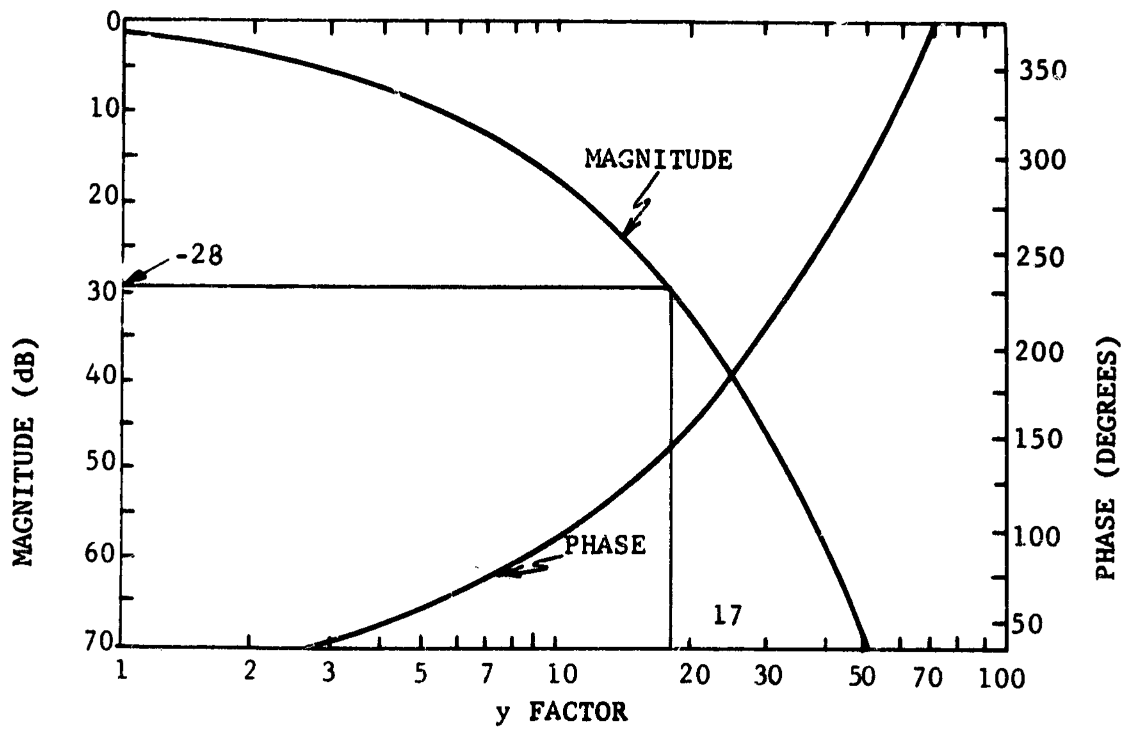
The final CAS transmitter to aircraft ATC receiver interference situation to be investigated involves a CAS transmitter on one aircraft versus an ATC receiver on a different aircraft. During the major portion of a flight the SST will be flying at such an altitude that no aircraft will be expected to be flying above it. Since the ATC antenna with a gain of 12 dB will be generally oriented in the upwards direction the threat of interference will be minimal for a major portion of the flight due to the directional characteristics of the ATC antenna and the shielding afforded by the airframe. After takeoff and before landing, another aircraft could be at a higher altitude. A frequency versus distance computer program output for this situation indicates that a frequency separation of 18.5 MHz will provide an S/I = +20 dB for airplane separations of 10 miles or more.

The ATC transmitter is assumed to have a fairly narrow emission spectrum and the probability of interference into the CAS receiver from an ATC transmitter is far less than for the reverse situation just discussed.

It is recommended that a frequency separation of at least 20 MHz be maintained between the CAS equipment and the ATC equipment. Since the CAS is tentatively scheduled to operate at four frequencies, 1575, 1580, 1585 and 1590 MHz as shown in Figure 9, the ATC equipment could be assigned the range from the lower limit of the radio navigation band at 1540 MHz up to 1555 MHz. This assignment provides the recommended 20 MHz frequency separation between the two L-band services and gives the ATC a 15 MHz bandwidth in which to operate.



(a) COUPLING VERSUS y FACTOR (LOW RANGE)



(b) COUPLING VERSUS y FACTOR (HIGH RANGE)

FIGURE 7

ADDITIONAL COUPLING DUE TO CYLINDRICAL CONSIDERATION

3.1.3 The Identification of the Major EMC Capability Limitations and Voids

A STUDY OF POTENTIAL INTERACTIONS POINTS TO NEEDED CAPABILITIES

Aerospace frequency engineering problems are compared to existing capabilities for analysis to identify the needed problem solving capabilities.

The sample problem examined in section 3.1.2 showed the need for good representations of transmitters and receivers considered for both the design and off-tune or nondesign portions of emission spectrums and responses. The example also showed that certain techniques and studies are available to aid the compatibility engineer looking at an aerospace EMC situation. The EMC problem expands rapidly in size when the many environmental emitters and receivers within radio line of sight of a high altitude aircraft are considered as shown in Figure 10. An even larger area of the earth is in view of a satellite at synchronous orbit altitudes. The number of possible interference couplets which should be considered in a complete analysis indicate the usefulness of an environmental data base and an automated aerospace systems analysis tool.

Figure 11 shows just the desired links for some L-band aerospace systems. The addition of possible interference couplets between the indicated equipments as well as the cosite possibilities for interference point the way to a variety of required problem solving capabilities. During this study, the capabilities required for aerospace EMC problem solving have been compared with the known existing capabilities and the results presented in Table 3 show both the available and the needed capabilities. Detailed discussions of each of the items listed in Table 3, are contained in the following sections of this report.

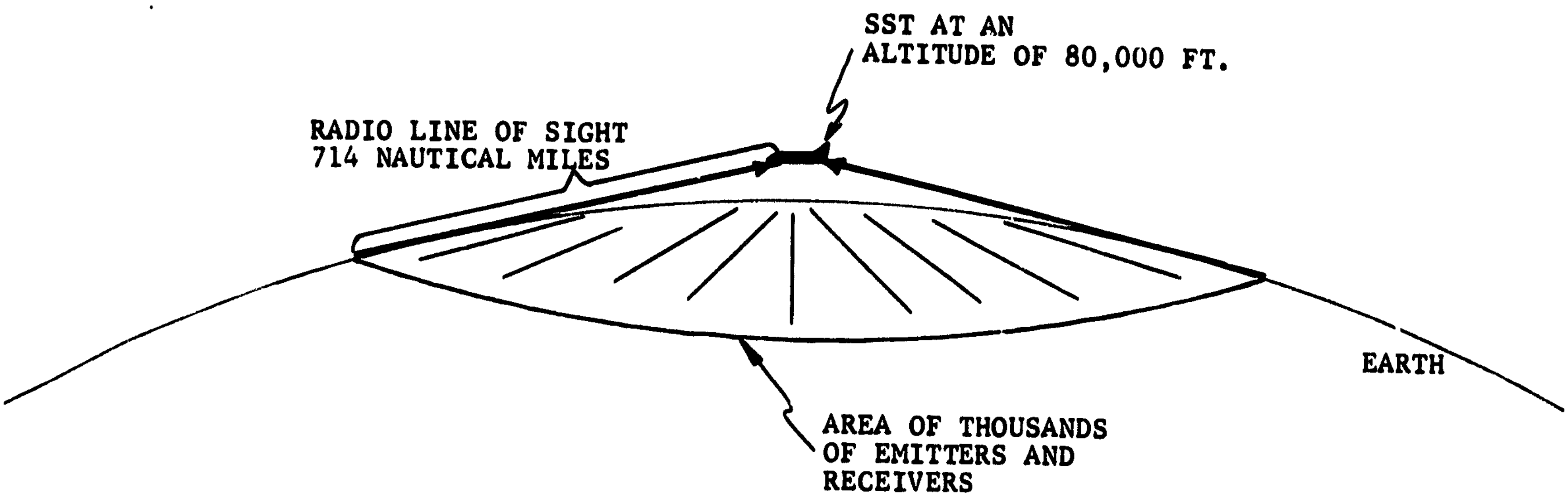


FIGURE 10

SST GROUND INTERFERENCE CONSIDERATIONS

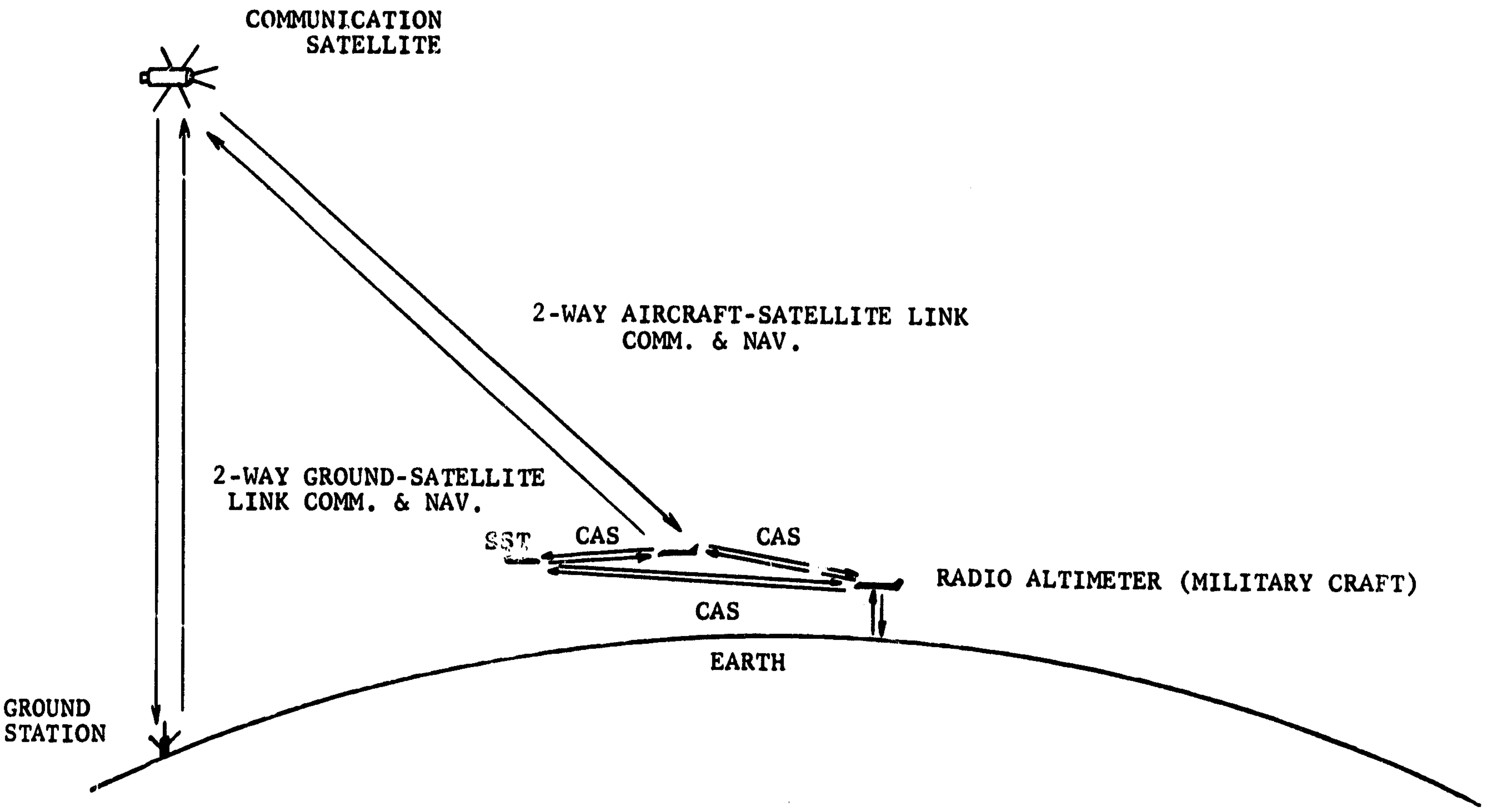


FIGURE 11

L-BAND AEROSPACE SYSTEMS

TABLE 3

AEROSPACE FREQUENCY ENGINEERING PROBLEMS VERSUS AVAILABILITY OF PROBLEM SOLVING CAPABILITIES

Problem Solving Capabilities	Aerospace Frequency Engineering Problems				
	On-board Satellites, Space Vehicle or Aircraft	Ground-to-Satellite and Satellite-to-Ground	Aircraft-to-Satellite	Aircraft-to-Aircraft	Aircraft-to-Ground and Ground-to-Aircraft
Cosite, Near Field and Nonlinear Mixing Models	Required and Not Avaliable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Transmitter Emission Spectra Models	Required and Partially Available	Required and Partially Available	Required and Partially Available	Required and Partially Available	Required and Partially Available
Receiver Filter, Modem and Signal Processing	Required and Not Available	Required and Not Available	Required and Not Available	Required and Not Available	Required and Not Available
Channel Characterization Models	Required and Partially Available	Required and Partially Available	Required and Partially Available	Required and Partially Available	Required and Partially Available
Antenna Radiation Pattern Models	Required and Partially Available	Required and Partially Available	Required and Partially Available	Required and Partially Available	Required and Partially Available
Environmental Data Bases	Not Applicable	Required and Partially Available	Required and Partially Available	Required and Partially Available	Required and Partially Available
Equipment Characteristics Data Bases	Required and Not Available	Required and Partially Available	Required and Partially Available	Required and Partially Available	Required and Partially Available
Automated Aerospace Systems Analysis Models	Required and Partially Available	Required and Not Available	Required and Not Available	Required and Not Available	Required and Not Available

3.2 A Summary of Existing EMC Analysis, Measured, Environmental, and Equipment Characteristics Data Capabilities

3.2.1 EMC Analysis Capability

THE EXISTING EMC ANALYSIS CAPABILITY IS NOT ADEQUATE FOR THE ANALYSIS OF NASA AEROSPACE EMC PROBLEMS

A survey of available EMC analysis techniques indicates a lack of direct applicability to those peculiar EMI problems encountered with satellites and high performance aircraft such as the SST.

This phase of the study was concerned with collecting and summarizing data concerning existing system, transmitter, receiver, antenna and channel models and determining their applicability to aerospace RFI problems. The potential interference situations for which analysis tools were sought included:

1. Cosite interference on-board space vehicles, satellites and aircraft.
2. Interference terrestrial emitters to space vehicles, satellites and aircraft.
3. Interference from airborne or spaceborne emitters to terrestrial receivers.
4. Interference from terrestrial emitters to satellite ground stations .
5. Inteference between airborne or spaceborne systems.

The sources for this data consisted primarily of available documentation from NASA, The Department of Defense's Electromagnetic Compatibility Analysis Center (ECAC), all branches of the U.S. Military Services, the Office of the Director of Telecommunications Management (ODTM), the Federal Communications Commission (FCC), the Interdepartment Radio Advisory Committee (IRAC), the International Telecommunication Union (ITU), the International Radio Consultive Committee (CCIR), the Joint Technical Advisory Committee (JTAC) and the open literature in the EMC/EMI/ Frequency Management area.

While many of the syntheses, models and programs uncovered in this search process have application to NASA aerospace RFI problems, as will be discussed in subsequent sections of this report, no single capability was without a serious limitation, making it unwieldy to apply directly to problem situations of the type mentioned. The major limitations constraining the direct use of existing EMC analysis capabilities include:

1. The existing EMC system models (the term "System Model" is defined in Section 3.2.1.1) do not contain a practicable method for analytically combining signals arriving simultaneously at the staellite location and assessing the effect of these multiple interference signal inputs on aerospace receivers.

2. These system models have no facility for treating the time-variant interference problem generated by the movement of a satellite in orbit or an aircraft in flight.

3. The majority of the more applicable system models require a large environmental file of electronic systems as input. It has already been established during the period of this study that the acquisition of these environmental files, namely the DOD's Environmental Equipment File and Equipment Nominal Characteristics File for use by NASA, will be an extremely difficult, if not impossible process. Thus use of these models without major programming modifications will be difficult.

4. None of the system models investigated are of a completely statistical nature. That is, some models are

completely deterministic while others have pseudo-statistical sub-elements such as the representation of antenna gain as a Gaussian random variable. The statistical combination of these mixed deterministic and probabilistic sub-element variables in the system models investigated was either not complete or not entirely correct.

5. In only a few of the system models investigated did the interference prediction go beyond the interference signal level, signal ratio or interference margin level. Those attempts at relating these levels to an electronic system performance measure, with few exceptions, were limited to radar PPI scope degradation and voice articulation index predictions. None of the models investigated had provisions for treating anti-clutter, anti-jam, AGC, AVC or limiter circuits such as might be found in a multiple access satellite communications system.

7. The transmitter emission spectra models available do not include considerations of fundamental and harmonic spectral shaping by the transmitter signal generation or power amplifier circuits. No estimates of spectral floor levels are available and the models used to represent harmonic levels are questionable because of the lack of validation measurements.

8. The receiver models examined amounted to little more (with a few notable exceptions) than linear filter models representing the RF and IF sections of the receivers. The use of two-signal selectivity models, considerations of desensitization, saturation, intermodulation, spurious responses and other nonlinear phenomena was rare, except in the identification of nonlinear response frequencies. Consideration of receiver adjacent channel and out-of-band responses was almost entirely limited to a linear filter theory approach in the

"power domain". That is, very little evidence was given of an attempt to model the voltage spectrum phase response of receiver networks either for the out-of-band or in-band selectivity such that interference signal phase distortion might be accounted for.

9. The channel models investigated, in almost all cases, gave consideration only to the basic path loss or signal attenuation between transmitter and receiver. Little consideration was given to the frequency selective properties of the propagation medium resulting from multipath or fading. Those channel models containing considerations of other than receiver thermal noise, such as atmospheric noise that might occur in the VLF/LF - HF frequency ranges treated this noise in a deterministic manner. Nc quantitative consideration of man-made noise was included in the models investigated.

A summary of the system, transmitter, receiver, and antenna models examined in this phase of the study is presented next.

3.2.1.1 System Models for EMC Analysis

INTERFERENCE EVALUATION VIA COMPUTER SIMULATION

The system models surveyed do not have a great deal of direct applicability to NASA aerospace EMC problems. However, many of the prediction techniques can be used to implement a special purpose aerospace EMC evaluation tool.

System models for EMC analysis, as defined here, include those digital and analog computer simulations of an interference situation. The situation includes the potential interference sources and victims, their electronic, geographic and operational characteristics and usually, some description of the channel via which interference is suspected to couple these victims and sources together. The existing models are usually generalized, that is, they have been designed to accomodate or represent a wide range of equipment types, geographic locations, operational modes and channel conditions. Beyond this very general description, the survey of system models uncovered seven distinct categories into which these models may be fit. These categories are:

1. Classical Cull and Prediction Models
2. Statistical Summarization Models
3. Frequency/Distance Separation Models
4. Frequency Situation Models
5. Geographic and Environment Condition Display Models
6. Special Purpose Prediction Models
7. Analog Simulation Models

The first category, "Classical Cull and Prediction Models" include those massive digital computer simulations such as ECAC's Master System Simulator (MSS-2) or RADC's

Interference Prediction Process (IPP-1) both classified as "cull" programs and ECAC's Technically Improved Interference Processing System (TIIPS) classified as a "prediction" process. The difference between "cul " and "prediction" was found to be more of a semantic illusion than a reality. The degree of refinement used to represent the sub-models (e.g., propagation, transmitter emission spectra) being the intended distinguishing factor. In general, "cull" models are simpler representations of the interference situation that employ generally conservative estimates of the physical factors and are used in the early stages of problem solution when there are a large number of interactions to consider and the desire is to rule out interactions that have a remote likelihood of producing interference. The more refined models, sometimes called "prediction processes", are characterized by a more precise representation of characteristics and are usually applied to analyze the residue environment which has been reduced by the "cull" model. Each of the models mentioned performs a one-to-one evaluation for each victim receiver. That is, the interference potential of each environmental transmitter is tested separately. In none of the models evaluated was there any procedure for evaluating the cumulative effects of many transmitters on a single receiver. This was considered a serious limitation, since satellite and aircraft would surely be exposed to more than one interference signal at any one time. The system equations used in the models are very simple and take the form,

$$P_D = P_T - A_e - L \quad \text{(MSS-2)} \tag{2}$$

$$I/N = \int_{f_1}^{f_2} P_T\,(f+\Delta f)\,\left|H(f)\right|^2 df \;+ G_R + G_T - L - N_R \quad \text{(MSS-2, TIIPS)} \tag{3}$$

$$S/I = S/N - I/N \quad \text{(TIIPS)} \tag{4}$$

$$P = P_T + G_T + G_R - L - P_R \quad \text{(IPP-1)} \tag{5}$$

where P_D = the spatial power density at the location of the victim receiver

P_T = the transmitter power of the potential interference emitter

A_e = the effective aperture of the transmitting antenna

L = the propagation path loss between transmitter and receiver

I/N = the interference-to-noise ratio at the output of an equivalent linear filter having the selectivity of the victim receiver

$P_T(f+\Delta f)$ = the power spectral density of the interfering transmitter

$\left|H(f)\right|^2$ = the selectivity function of the victim receiver

N_R	= the receiver noise power, minimum discernable signal
S/N	= the signal-to-noise ratio in the victim receiver taken at the same point where the I/N is predicted
P	= the interference margin, or the amount by which the interference power exceeds the minimum power required to produce interference in the receiver
G_T	= the transmitter antenna gain in the direction of the transmitting antenna
P_R	= the minimum power required to produce interference in the receiver

The results of these computations, namely the power density at the receiver location, the I/N or S/I at the output of the equivalent receiver filter and the interference margin are then compared against a single user specified threshold for these parameters and those transmitters or receivers exceeding this level are then culled. In none of the models investigated were these cull thresholds set automatically and individually in a transmitter/receiver case by case basis, taking into consideration such obvious factors as transmitter modulation type and receiver signal processing. The philosophy behind this approach is that the "analyzer" should reflect these factors in his choice of cull threshold. This is considered most unrealistic since this forces the user to determine or have available beforehand these individual cull thresholds for distinct transmitter/receiver couplets sometimes numbering in the hundreds. It was also noted that none of the models investigated had, even for the single threshold case, a provision for setting this threshold based on a user specified risk, that is, an allowable error probability of not culling a transmitter or receiver which has an interference potential. Thus, while the cull thresholds are usually set on the conservative side, such as to hopefully not miss any potential interference systems, there is no quantitative measure of this conservatism.

Considerations of detection, post-detection, anti-interference, anti-jam circuitry were minimal in the system models investigated. The MSS-2X, a post processor for the MSS-2 system does allow a prediction of plan position indicator (PPI) scope clutter condition based on the number of detected radar pulses after weighting the results of the MSS-2 output with some very questionable antenna mutual gain function. The Communication-Radar System Model of the U.S. Army Electronic Proving Ground does predict voice articulation index as a function of interference signal characteristics. This points to the fact that the existing models have no provision for predicting the performance of the newer digital systems which are becoming more commonplace in aerospace applications and which often employ either block or convolutional codes for noise protection and thus have some inherent interference rejection qualities that cannot be simply accounted for by a signal ratio threshold alone.

The cull and prediction models investigated require large environmental and equipment characteristics files as input. These files which exist physically on magnetic tape, are presently structured so as to be compatible with the UNIVAC 1108 and GE 635 computers for the ECAC and RADC programs, respectively. While some tape conversion problems would be anticipated in the process of making the DOD/ECAC files compatible with the NASA/ERC 7094 II computer software, the major problem is not a technical one. Rather, it is that NASA will find it an extremely difficult, if not impossible process to convince the DOD to release these files to NASA for use in their EMC program. With this fact in mind, in order to make use of these programs, NASA would have to make some major modifications to the existing programs to work around this file unavailability.

All of the system models surveyed failed to couch the interference predictions in a completely statistical sense. The TIIPS (4) and IPP-1 (5) processes however, did have some provision for treating a few of the parameters in the system equation in a probabilistic manner. That is, they treat some of the parameters as random variables, always normally distributed when expressed in dBm or dB terms and statistically independent such that the interference parameter computed is also a normally distributed random variable whose mean and variance are simple to compute because of the assumption of independence.

The second category, "Statistical Summarization Models" includes those computer programs expressely written to access the large environmental and equipment characteristic files, compile information and tabulate or visually display the results. An example of these types of programs is ECAC's Effective Radiated Power (ERP) Spectrum Analyzer Program which utilizes as input an environmental file of the proper format, some user specifications regarding the frequency extent of the tabulation and the values of ERP for which the program is to count the number of file entries meeting specifications. For example, Figure 12 illustrates a fictitious count of all radar emitters in the continental United States operating between 1400-1500 MHz in 10 MHz bands with an ERP in excess of

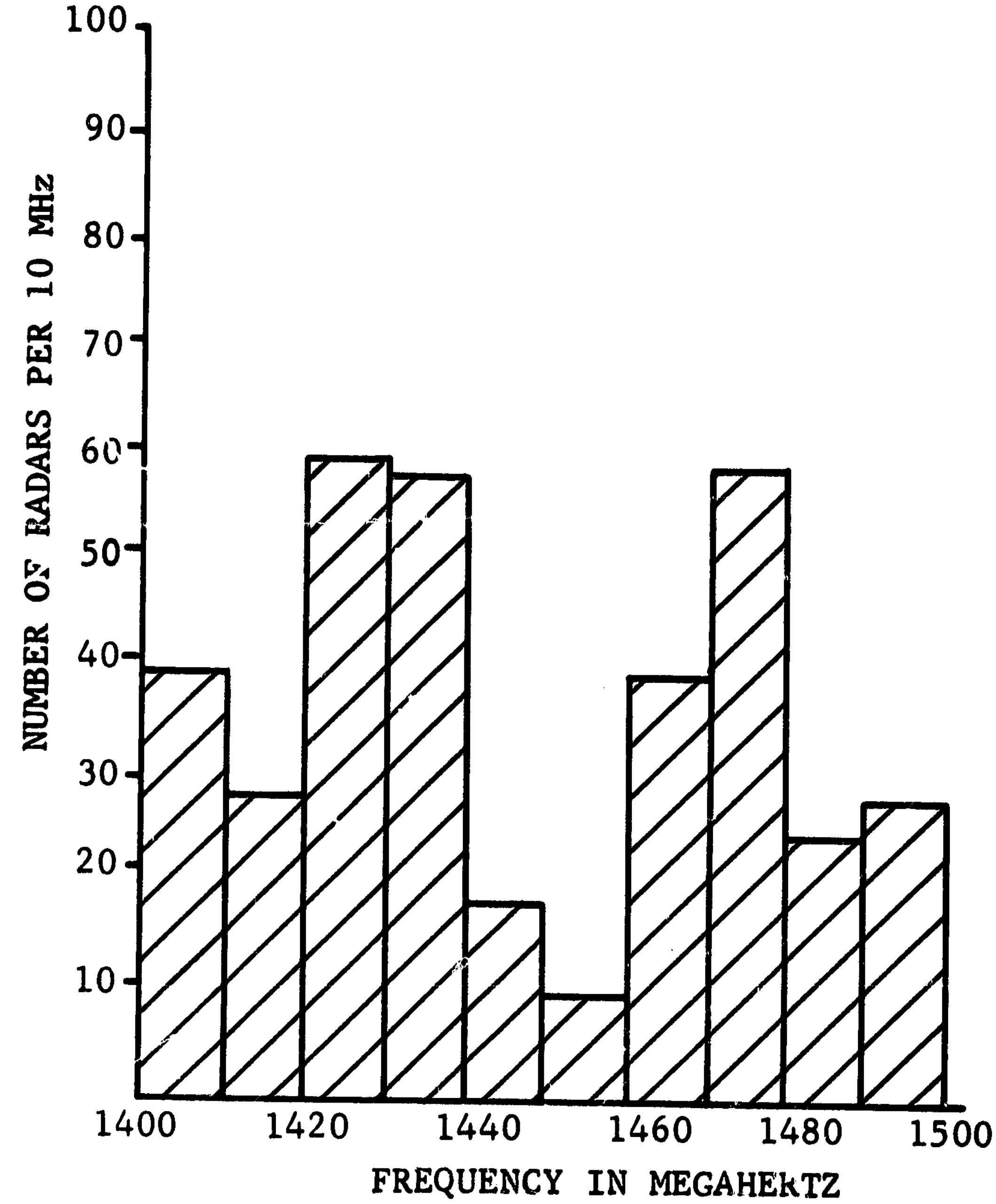


FIGURE 12

HYPOTHETICAL U.S. RADAR EMITTERS BETWEEN 1400 AND 1500 MHz WITH ERP'S IN EXCESS OF 90 dBm

90 dBm. This type of data might be used to determine the potential problem inherent in placing a synchroneous satellite overlooking the U.S. in this frequency band. These programs have great value in being able to semiquantitatively evaluate the impact of placing a new aerospace equipment in a band where operation is shared with other users. Again, the applicability of empolying these types of programs for EMC analysis depends greatly on the availability of a data base.

The third category, "Frequency/Distance Separation Models" represents those computer programs designed to allow the EMC analyst to trade tuned frequency separation between a transmitter/receiver pair for distance separation between the two. It also allows the user to optimally adjust these two factors for various signal design options the communication system designer might have available. For instance, if distance separation is constrained by real estate limitations and tuning range by the choice of a narrowband power amplifier, then the analyst, using the frequency/distance separation routine can determine what desired transmitter power is required to operate satisfactorily in the presence of interference. Figure 13 is an illustration of the example just discussed.

The fourth category, "Frequency Situation Models", includes those programs designed to answer the question, what are the frequency interactions possible between a system of interest and an environment of electronic equipments. Mutual interference charts (Figure 14), capable of displaying all of the fundamental, image, and spurious response frequencies of a receiver as a result of single or multiple environment emitters are an example of these types of programs.

The fifth category, "Geographic and Environment Condition Display Models", contains those programs which display environmental equipment density, topographic shielding or spatial power density on a map of the geographic area of

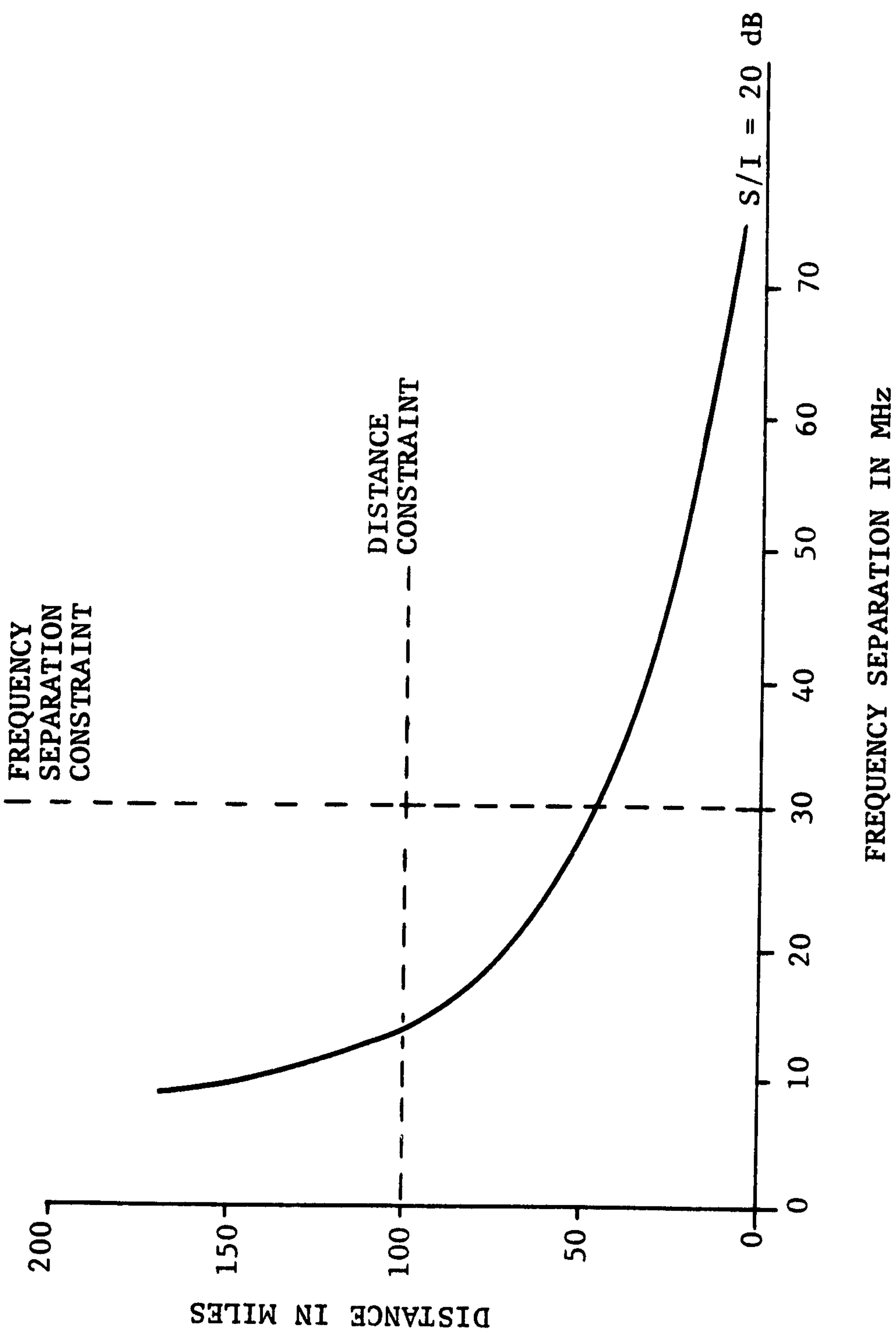


FIGURE 13

EXAMPLE OF A FREQUENCY - DISTANCE SEPARATION MODEL

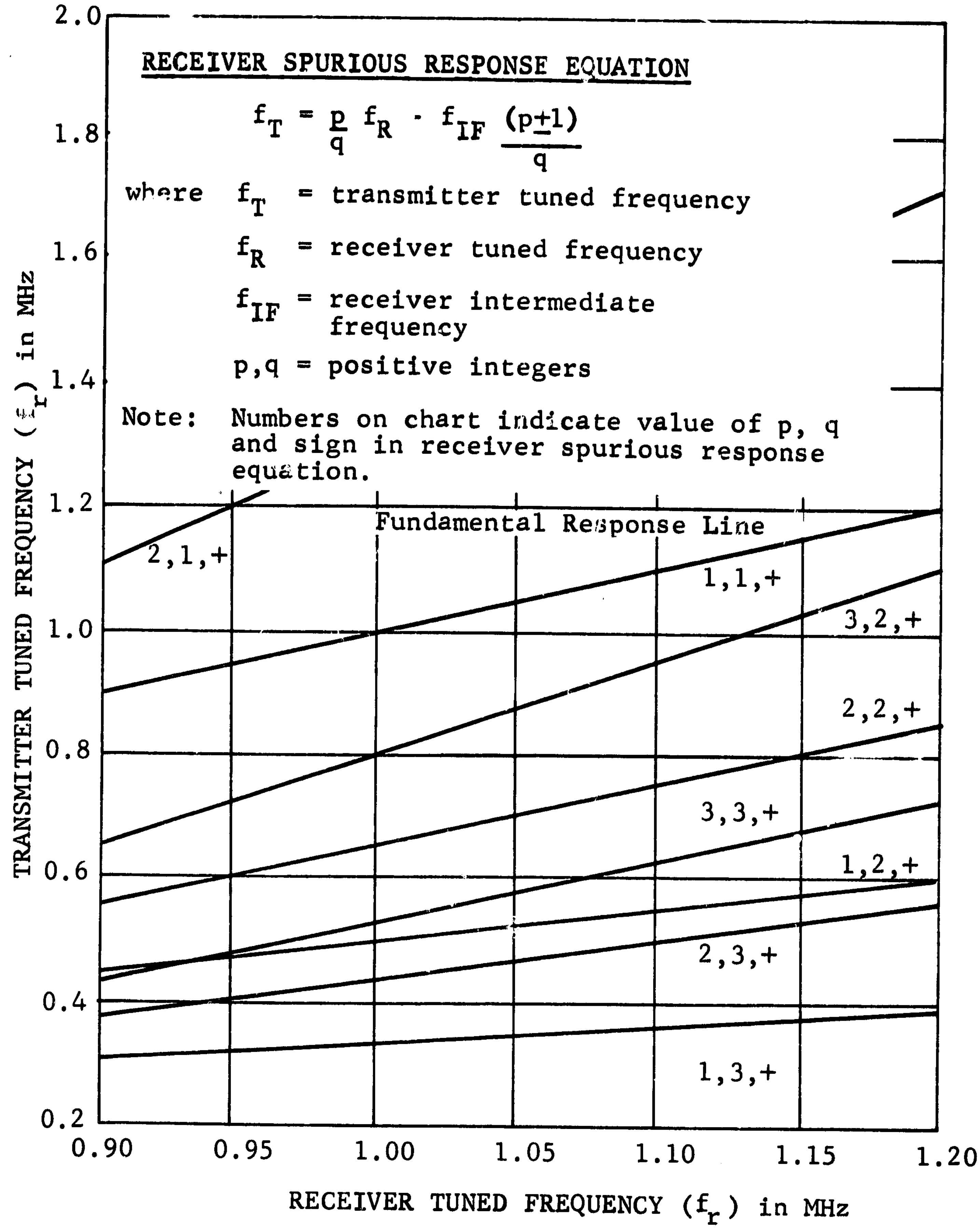


FIGURE 14

MUTUAL INTERFERENCE CHART

interest. Three especially important programs of this nature are ECAC's Distance Density Generator, Geographic Cell Nomenclature Density Generator and Site Analysis Model programs. The first of these programs accepts as input an environmental file of proper format and counts the number of equipments of a particular nomenclature, frequency or any other number of parameters, located in annular rings of a user specified length about any given geographic location. The second of these programs is the same as the first, except that the equipment count is conducted within any geometric area about the site, that can conveniently be approximated by rectangles. The last of these programs is particularly interesting in that given as input, ECAC's Topographic Data File, it has the capability to display on a suitable map overlay of a given geographic area the shielding afforded to, say, a satellite tracking station by the natural terrain. The program also has been designed to produce a spatial power density display on these maps as well. Illustrations of these two latter capabilities are shown as Figures 15 and 16, respectively.

The sixth category, "Special Purpose Prediction Models", includes those programs not entirely general in their scope of application but noteworthy in their potential applicability to aerospace EMC problem analysis. The ECAC Search Radar Prediction program, the U.S. Army Electronic Command's Radio Interference Prediction by the Statistical Terrain Method program, NASA's Space Vehicle Broadband Near-Field Electromagnetic Interference Model program, and the U.S. Army's Digital Computer Program for Determining the Effect of High Level RF Exposure on Missile Systems are examples of these types of programs.

The seventh and final category, "Analog Simulation Models",

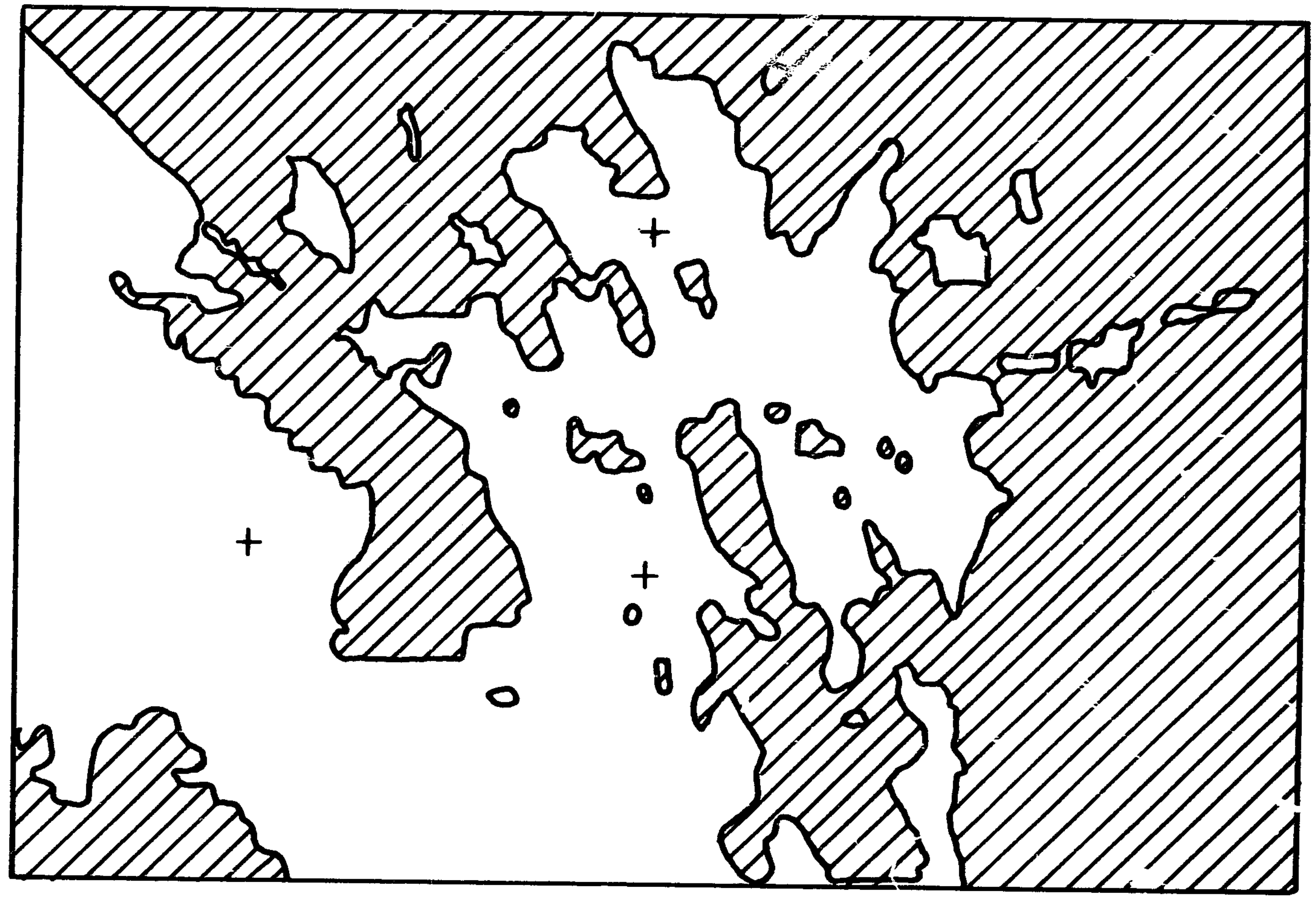


FIGURE 15

SITE ANALYSIS MODEL

(Illustration shows topographic shielding about those sites indicated, + indicates sites)

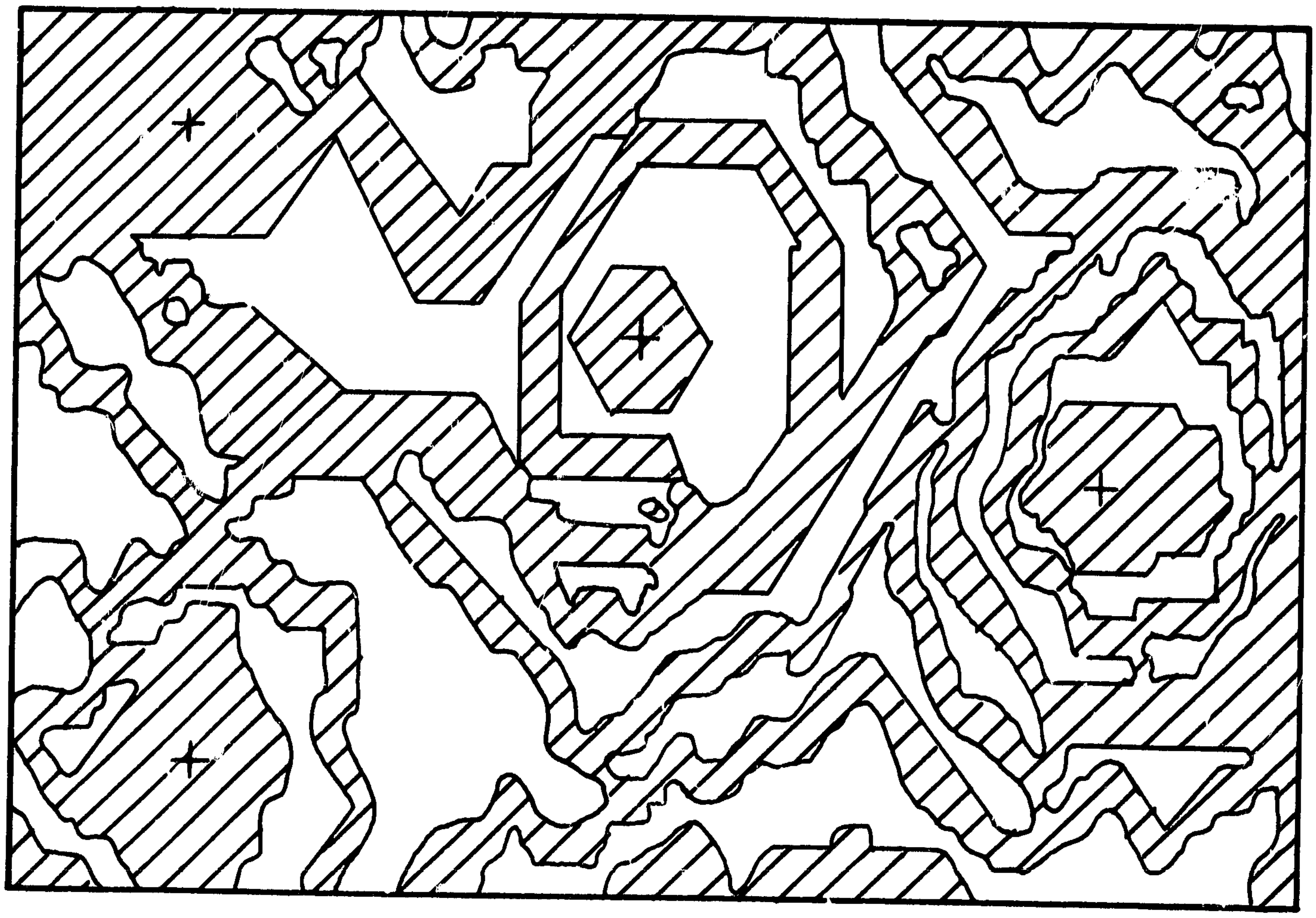


FIGURE 16

POWER DENSITY DISPLAY

(Illustration shows contours of spatial power density in excess of user specified power density threshold about sites indicated, + indicates sites) includes those programs that attempt to evaluate the interference potential of an interference situation by exposing a hardwired versus mathematical simulation of a victim receiver to one or more real signals and observing the output to determine the degree of system degradation. The most outstanding example of this approach to EMC analysis is the General Electric Electronic System Evaluator (GEESE). The GEESE system involves building an analog model, in the form of a low frequency replica of the receiver to be analyzed and recording the output of the simulated receiver on brush type paper, simulating an A-scope display, after inputing a desired and undesired signal. It is quite unfortunate that this very powerful form of EMC system analysis tool has not been used more often since it represents a quick and convenient method of predicting receiver performance in those cases where the analysis process becomes mathematically intractable.

Table 4 is a summary of the characteristics of those system models surveyed during the course of this study.

TABLE 4. SUMMARY OF SYSTEM MODELS FOR EMC ANALYSES

Model	Developing Agency or Firm	Class of Service to Which Model is Applicable	Applicable Frequencies	Model Input Data Sources	Model Outputs	Interference Mechanisms Considered	Threshold Criteria	Propagation Models Available	Probabilistic	Automated	Validated
Master Systems Simulator-2 (MSS-2)	ECAC/IITRI	General	HF through Microwave	ECAC	Couplets Meeting Power Density or I/N Thresholds	Co-Channel, Adjacent Channel Spurious Responses, Harmonics	Power Density or I/N in Excess of Threshold	SCSE, CRPL	No	Yes	Partially
Technically Improved Interference Processing System (TIIPS)	ECAC/IITRI	General	HF through Microwave	ECAC	Couplets Meeting Power Density or I/N Thresholds	Co-Channel, Adjacent Channel Spurious Responses, Harmonics	Power Density or I/N in Excess of Threshold	SCSE, E?M-1	Mixture	Yes	No
Off-Frequency Distance Criteria-2,3 (ODC-2,3)	ECAC/IITRI	General	General	ECAC	Frequency Separation Versus Distance Required for Specified S/I, S/N or I/N	Co-Channel, Adjacent Channel, Harmonics	—	Modified SCSE	No	Yes	Yes
Mutual Interference Chart Generator (MIC)	ECAC/IITRI	General	General	ECAC	Mutual Interference Chart	Co-Channel and Spurious Responses	—	—	No	Yes	Yes
Search Radar Prediction (SRP)	ECAC/IITRI	Pulsed Search Radar Systems	Microwave Radar Bands	ECAC	Distribution of Interference Blips on the PPI of the Victim Receiver. Probability Distribution of the Interference-to-Noise Ratio at the Output of the Victim Receiver. I/N of the Interference Accepted by the Tuned Response and each of the Spurious Responses of the Receiver	Co-Channel, Adjacent Channel, Harmonics Spurious Responses	—	SCSE	Mixture	Yes	No
L-69 Multi-Preprocessor	ECAC/IITRI	General	General	ECAC	Environmental Listing of Systems Exceeding Power Density Threshold	Co-Channel	Power Density in Excess of Threshold	CRPL, Modified SCSE	No	Yes	Yes
Effective Radiated Power Spectrum Analyzer	ECAC/IITRI	General	General	ECAC	A Histogram Indicating the Number of Interferers Operating in a Given Frequency Cell that Exceed One or More Effective Radiated Power Thresholds	— —	Effective Radiated Power and Tuning Range Overlap of Specified Frequency Cells	—	—	Yes	—
Master System Simulator-2X (MSS-2X)	ECAC/IITRI	Pulsed Radars	General	ECAC	Scope Condition. Amplitude Distribution of Interference Pulses. Amount of Receiver Desensitization	—	—	User Specified	Mixture	Yes	Partially
Site Analysis Model (SAM)	ECAC/IITRI	General	General	ECAC	Topographic Map Showing Shielding Surrounding a Ground Site	—	—	Free Space	No	Yes	No
Distance Density Generator	ECAC/IITRI	General	General	ECAC	An Equipment Count by Nomenclature in Specified Annular Rings About a Site	—	—	—	—	Yes	—
Geographic Cell Nomenclature Density Generator	ECAC/IITRI	General	General	ECAC	An Equipment Count by Nomenclature in Square Map Grids	—	—	—	—	Yes	—
Interference Prediction Process (IPP-1)	RADC/ARC	General	HF through Microwave	USAF/ECAC	Couplets Meeting Interference Margin or Probability of Interference Criteria	Co-Channel, Adjacent Channel Spurious Responses, Intermodulation Harmonics	Interference Margin in Excess of Threshold. Probability of Interference	Free Space, Surface Wave Skywave, Diffraction Tropospheric Scatter	Mixture	Yes	No
AT&T Long Lines Model	Bell System	Microwave Relay Service	4, 6, 11 GHz	AT&T and FCC	Couplets Meeting 96 dB S/I	Co-Channel, Adjacent Channel	S/I > 96 dB	SCSE	No	Yes	Yes
Technical Considerations in the Assignment of Operating Frequencies in a Communications System	O.M. Salati and R.A. Rosien	Pulsed Radar Systems	Microwave Radar Bands	ITU and USAF	Frequency Separation Required for Various Ratios of S/I	Co-Channel, Adjacent Channel	S = I	Friis, Bullington and Gerks Models	No	No	No
Radio Interference Prediction by the Statistical Terrain Method	U.S. Army Electronics Command	Communications Systems	1 kHz - 33 GHz	U.S. Army	Statistical Failure Ratios. Histograms of Statistical Distributions of Transmission Distances and Signal Ratios	Co-Channel, Adjacent Channel	C/N in Excess of Threshold. Probability of Successful Receiver Operation in Excess of Threshold	Modified Egli Model	Mixture	Yes	No
Communication-Radar System Model	U.S. Army Electronic Proving Ground/Bell Aerosystems	General	HF through Microwave	U.S. Army	Articulation Index. Probability of Interference from Multiple Sources	Co-Channel, Adjacent Channel	Articulation Index or Probability of Interference in Excess of Threshold	Modified SCSE with Terrain Considerations	Mixture	Yes	Yes
GEESE	RADC/G.E.	General	General	USAF/NAVY	User Specified. Model is an Analog Simulation System Allowing a Wide Variation of Signal Inputs and Simulation of Receiver Networks	User Specified. All Linear Interference Mechanisms can be Simulated Easily. Non-linear Mechanism Simulation is Extremely Difficult	User Specified and Dependent on System Simulated	User Scales Down Interference Level to Account for Path Loss	No	Yes	Partia
Space Vehicle Broadband Near-Field Electromagnetic Interference Model	NASA/Boeing	Space Vehicles	General	NASA	Prediction of Cable-to-Cable Coupling	Radiation Coupling Between Equipment Boxes and Cables	I < 6 dB Below Susceptibility Level of Receptor Circuit	Free Space	No	Yes	No
Digital Computer Program for Determining the Effect of High Level RF Exposure on Missile Systems	U.S. Army/Vitro	Missile Systems	General	U.S. Army	Effect of Radiation is Plotted as a Function Frequency Versus Current in the Electrical Initiation or Termination of a Receptor Circuit	Direct Radiated emf's. Mutually Coupled Currents Impedance Unbalance Induced emf's	User Specified Current Threshold	Free Space	No	Yes	No

3.2.1.2 Transmitter Emission Spectra Models

THE FREQUENCY DISTRIBUTION OF POWER SPECTRAL DENSITY

Transmitter emission spectra models are critical elements in an interference evaluation since they are used, together with the receiver selectivity function, to predict the interference power at a point of interest within the receiver.

The survey of available transmitter emission spectra models focused on three related areas. The first was concerned with determining what syntheses were available to describe the fundamental emission spectra of transmitters around the tuned frequency. The second area of concern was with the out-of-band emission characteristics including transmitter harmonics. The third area concerned itself with the subject of transmitter intermodulation.

Table 5 is a listing of the transmitter syntheses of fundamental power spectra for which techniques presently are available. The spectra in the table are categorized by their modulation type and are identified in the table by their FCC modulation codes. The nominal transmitter data required to accomplish these syntheses are also listed.

The second phase of this survey, aimed at identifying available syntheses for transmitter out-of-band emissions and harmonics was much less fruitful. It was uncovered that some vanguard efforts were being persued, but that presently, there were two very elementary approaches to this problem. The first, an admittedly expedient and coarse method, simply reproduces the fundamental spectral shape at a reduced level of power spectral density (usually 60 dB below the fundamental emission) at the harmonic frequencies of the fundamental

TABLE 5

AVAILABLE TRANSMITTER SYNTHESES OF FUNDAMENTAL POWER SPECTRA

MODULATION TYPE	FCC MODULATION CODE	NOMINAL DATA REQUIRED FOR SYNTHESES
AM Voice (clipped and unclipped speech)	A3	Percent modulation, average output power
AM SSB	A3J	Percent modulation and sideband filter characteristics, average output power
PM Voice (indirect FM)	F3	Frequency deviation average output power
PM SSB	F9	Frequency deviation average output power
FM Voice	F3	Deviation frequency, average output power
Conventional Pulse Radar	PO	Pulse width, rise and fall times of pulse, peak pulse power
Pulse Compression	P9G	Pulse width, compression ratio and peak pulse power
FM-CW Radar (triangular and sawtooth waveforms)	F2	Total frequency deviation, modulation frequency and average output power
Binary Frequency Shift Keying (continuous phase at transitions)	F1	Bit rate, frequency shift, and average output power
Binary Frequency Shift Keying (two oscillators; discontinuous phase at transitions)	F1	Bit rate, frequency shift, and average output power

TABLE 5 CONT'D

MODULATION TYPE	FCC MODULATION CODE	NOMINAL DATA REQUIRED FOR SYNTHESES
Keyed Carrier Telegraphy	A1	Words per minute and average output power
Keyed Modulator Telegraphy	A2	Words per minute, modulation frequency, and average output power
PAM-FM	F9	Frequency deviation, average output power
SSB-FM	F3J	Peak frequency deviation and average output power

and completely ignores the problem of spurious emissions. This is basically the technique employed in ECAC's MSS-2 automated interference prediction system.

The second approach investigated, the most attrative and promising of the two, applies statistical techniques to large collections of measured data to fathom what equipment parameters influence the overall spectral characteristics. The measured data involved in the process is usually grouped according to some characteristic that is common to as many equipments as possible. Unfortunately, however, the number of categories has been limited by the necessity to include a reasonable number of samples in each category. The categories that have been examined include:

(1) Type of transmission line between the transmitter and antenna.

(2) The type of output tube (e.g., klystron, amplitron, etc.).

(3) Pulse width ranges (e.g., pulse width $< 1\ \mu$sec).

(4) Measurement contractor.

It is obvious that many other categories, possible of equal importance, have been overlooked. Among the additional classes of equipment categorization which should be investigated include:

(1) Transmitter power
(2) Modulation type
(3) Equipment age
(4) Transmitter output power per pound of equipment
(5) Rotary joint type (e.g., coaxial, waveguide)
(6) Antenna type, and
(7) Frequency

The mathematical model that is presently used to determine the amplitudes of the harmonic emissions is expressed by

$$P(nf_o) = A \log nf_o + B \quad (\text{for } n \geq 2) \qquad (6)$$

where

$P(nf_o)$ = the mean power at the n^{th} harmonic of the fundamental frequency, f_o, in dB below the fundamental

n = the harmonic number

A,B = constants determined from the statistical analysis for specific transmitters or transmitter classes

The search for methods used to predict transmitter intermodulation power also yielded two methods. The first is a pseudotheoretical approach developed by J. L. Eaves, et al. (6) In this technique, the transmitter intermodulation power of any order is expressed in terms of the measured third order low transmitter intermodulation power, the output power of the transmitter in which the intermodulation mixing occurs, and a coupling factor, $\alpha = P_i/P_o$, where P_i is the output power of the interfering transmitter. It is also dependent on the coefficients of the power series normally used to represent the input-output relationship of the nonlinear element in the transmitter was well as the transfer function of the output circuit of the transmitter.

The second approach utilized the fact that the amplitude associated with intermodulation outputs is a function of the power level of the two signals that mix to produce the output and an intermodulation constant related to the particular set of conditions that produce the output. The expression relating these variables is given by (7)

$$P_{nm} = nP_1 + mP_2 + C_{nm} \qquad (7)$$

where

P_{nm} = intermodulation output power in dBm

n,m = integers

P_1 = power level of one transmitter in dBm

P_2 = power level of other transmitter in dBm

C_{nm} = power level of other transmitter in dBm

The parameter C_{nm} is a normally distributed random variable reflecting the variability of the intermodulation output powers for different transmitters of the same class.

3.2.1.3 Receiver Synthesis Models

THE FREQUENCY DISTRIBUTION OF RECEIVER RESPONSES

Special consideration given to modelling of receiver selectivity functions and nonlinear responses can lead both to less conservative estimates of the interference potential and to the identification and evaluation of less obvious receiver interactions.

The survey of available receiver synthesis models is centered on three areas of concern. The first phase of the survey investigated those techniques used to model the RF and IF selectivities of receivers. The second phase was concerned with determining what techniques were available for predicting spurious response frequencies and levels. A final survey investigated the availability of techniques for predicting receiver intermodulation frequencies and power levels.

The generalized modelling of RF filters has taken two courses. These models have followed either a lumped constant circuit theory approach or a statistical treatment aimed at obtaining the means and variances of measured RF characteristics. The lumped constant circuit theory approach has lead to three specific models. These are the Butterworth, Chebycheff, and an n-stage stagger-tuned and synchronously-tuned models. It appears that the modelling of RF filtering, at least at the ECAC, is being done using some form of the n-stage synchronously-tuned model. An expression for an RF selectivity function utilizing the model is given by,

$$H(f) = \prod_{j=1}^{n} \left\{ \frac{1}{1 + \left[Q_j \, \frac{(f + f_r)\;(f - f_r)}{(f)\;\;(f_r)} \right]^2} \right\}^{1/2} \tag{8}$$

where

- $H(f)$ = the relative response of the network at f
- Q_j = the Q of each tuned circuit
- f = the frequency at which the response of the network is desired
- f_r = the resonant frequency of each tuned circuit (assumed equal for each circuit)
- n = the number of tuned stages

This representation has the basic disadvantage that; (1) the parameters Q_j and f_r are difficult to obtain and are not typical (at least at present) of characteristics stored in any known equipment nominal characteristics file; and (2) the representation is valid primarily in the frequency range immediately surrounding the receiver-tuned frequency and is thus of little value in adjacent signal interference predictions. For these reasons, increased attention has been focused recently on the use of measured data from which statistical inferences can be made about the RF selectivity function. Unfortunately, however, in the past RF selectivity characteristics have been difficult to measure at VHF and microwave frequencies because of the limited dynamic range of existing measurement instruments, with the result that little measured data exists. However, there does exist, in the investigative phase, a technique for measuring RF selectivity that is expected to yield a nominal amount of measured data in the near future from which a statistical synthesis model will result. The selectivity model that will be used in this statistical synthesis is of the form

$$H(f)_{dB} = A \log \left[1 + B \frac{\Delta f}{f_o} \right]^2 \qquad (9)$$

where

$H(f)_{dB}$ = the relative selectivity of the RF network in dB

Δf = the frequency deviation from the on-tune position at which the relative selectivity is to be predicted

f_o = the RF tuned frequency of the network

A, B = the constants that are evaluated for a particular receiver class by statistical methods

The general philosophy relating to IF selectivity modelling has been quite similar to that used for the RF stages. That is, both a lumped constant circuit theory approach and a model based on averages and variances of measured characteristics have been and are used. The basic difference between the two is that while statistical analyses of RF selectivities have been hampered by a lack of adequate measurement techniques, the IF selectivity functions have come under more detailed analyses because of the low operating frequencies of IF networks. Recent statistical studies of IF selectivities at the ECAC have met with limited success. Measured data for twelve communication system nomenclatures were analyzed by grouping them together according to the categories of receiver function, modulation type, and frequency range. In all cases, the standard deviation about the computed mean selectivity curves turned out to be too large for modelling purposes. The data are being regrouped, analyses of variance are being performed to determine what parameters bias the results, all with the objective of reducing the variation of the resulting characterization.

The investigation of models for predicting receiver spurious response levels uncovered a number of models of varying degrees of complexity used to synthesize response levels. The most pessimistic model, used almost exclusively for cull purposes, is the single level model which portrays all spurious response sensitivities as being usually 60 dB (or any other value equal to some specified minimum spurious rejection) above the fundamental response sensitivity. A slightly more refined model is the single slope model. This model, based on empirical data, has a spurious response sensitivity given by

$$L = 1.5\, p + 6\, q + 53.0 \qquad (10)$$

where

L = the spurious response rejection in dB below the fundamental sensitivity

p = an integer representing the harmonic order of the local oscillator

q = an integer representing the harmonic order of the interference signal

This model has been automated and presently serves as the cull capability in ECAC's MSS-2 Interference Prediction Model for predicting spurious response levels.

The third model often discussed, but rarely used to predict spurious response levels, is the classical analysis whereby the output response levels at the various spurious frequencies is obtained as a function of the input signal amplitude, the coefficient of the power series used to represent the nonlinear device (usually a diode-mixer) and the various mixer circuit filter transfer characteristics. This type of analysis suffers from the limitation that the accuracy of the model is limited by the use of an assumed set of values for the power series coefficients. There has recently been accomplished a noteworthy analysis of a typical diode mixer circuit with a resistive load (8). The purpose of the analysis was to determine analytically the power series coefficients. A technique known as the reversion of a power series is used in this analysis to determine the coefficients of the series. This technique shows considerable promise both as a relatively simple method for use in computing receiver spurious response levels as well as a useful guide for receiver designers that are possibly faced with the problem of attempting to reduce a particular undesired spurious response. It is well known that mixer attenuation to an n^{th} order response is maximum when the n^{th} order coefficient is zero. This reversion process identifies the coefficients and, thus, shows what relation between the mixer parameters is necessary to minimize this undesired response.

The third and last phase of the receiver survey concerned itself with existing techniques for predicting receiver intermodulation levels. It turns out that the methods used to predict intermodulation and spurious response levels are essentially the same. The basic difference between the two phenomena is that in receiver intermodulation, two or more undesired signals, with or without the receiver local oscillator beat across a nonlinear device to produce the undesired response. Spurious responses, on the other hand, have been defined as a receiver response involving one undesired signal and the local oscillator signal or one of its harmonics. This similarity is quite evident when one considers that two sine waves, even of different frequency, can be combined into a single sinusoidal function.

There are two approaches to this problem of receiver intermodulation that warrant special attention. The first is, again, the classical power series approach resulting in a model where, not unexpectedly, the receiver intermodulation response levels are a function of the input signal levels and the coefficients of the power series (9). The second approach (10) is attractive for a number of reasons. It is usually inconvenient and sometimes impossible to measure the value of ac oscillator voltage across the diode which is required in the classical approach. Also, the values for the diode parameter and the diode reverse leakage current that best fit the diode voltage versus current (E-I) curve must be determined or assumed. Measurements that can be taken easily are the insertion loss of the desired mixing product, the diode bias current, and the dc E-I characteristic of the diode. This method derives theoretically and from these limited measurements, the values of, (1) local oscillator voltage, (2) output resistance, and (3) diode reverse leakage current, a simple expression for computing intermodulation output power.

3.2.1.4 Antenna Models for EMC Analysis

SATISFACTORY MODELLING TECHNIQUES NOW EXIST FOR MANY ANTENNA CONFIGURATIONS

Many measurements have been made on medium and high gain antennas primarily in the microwave region. These measurements have been used to generate both quantized and statistical models.

The DOD's spectrum signature collection program has provided ECAC with a large data base of two dimensional radar antenna patterns. The majority of pattern data were taken for 360° of azimuth in a plane including the main beam. On certain radar nomenclatures the antenna patterns included cuts at vertical angles other than 0°. The patterns taken with the main beam elevated to vertical angles of 10°, 20°, and 30° above the horizontal, contributed knowledge about the configuration of three dimensional pattern. The spectrum signature collection standard MIL-STD 449, requires antenna pattern measurements for radar equipments but not for communications equipments, hence the large data base for microwave antennas and the practically nonexistant data base for vertical whips, long wires, log periodics, etc. Fortunately, the Naval Electronics Laboratory has gathered a large amount of shipboard antenna patterns for various antennas used in the communications frequency range.

The two level, two dimensional antenna model is the simplest representation of a high gain antenna pattern used for EMC problem solving. The model is based on the main beam gain and the horizontal half power beam width of a given antenna type. The two levels are the main beam gain (for an azimuth angle slightly larger than the half power beam width) and the remainder of the azimuth plane is set at a side lobe level based on a relationship determined for the measured data. The side-lobe levels are determined with a different formula for the three ranges of main beam gain; below 10 dB, 10 to 20 dB, and above 20 dB. The two level representation is very useful for the large environment problems usually solved with a computer. It is used to speed the culling process where the number of possible interference sources are reduced using the more crude models, free space propagation, box car transmitter models, etc. Actually four level models have been devised and used by the ECAC for the process also. These consist of the mainbeam level and three different side-lobe levels to make up the full 360° azimuth representation. Figure 17 is a summary of the two and four level antenna models.

If the initial EMC problem is reduced to just a few antenna considerations, it is appropriate to use the best representation available including a measured antenna pattern if available.

Another factor which is usually considered for radar antennas is the fact that they either rotate, nod (as a height finder) or sector scan (as in gun or missile fire control). The fact that a potential victim receiver is periodically swept by the main beam of a transmitter must be considered in the actual degradation analysis of that particular couplet.

Dr. Johnson at the Georgia Institute of Technology completed a study on the statistical characteristics of radar antennas for the Bureau of Ships. The objective of this work was to determine the best representation of the mutual gain (or coupling) between two radar antennas or the gain of one rotating radar antenna without using the great amount of data needed to accurately represent the minor lobe structure.

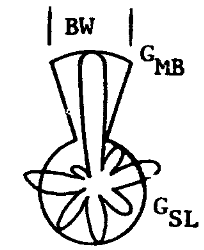
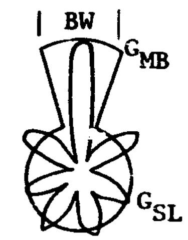
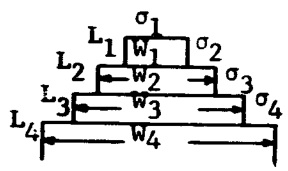
TYPE	INPUTS	GRAPHIC PRESENTATION	CAPABILITY
Two-level Two-Dimensional (Conservative)	1. Main Beam Gain 2. Half-Power Beam Width 3. Dynamic Operation		1. Cull 2. Reducing Problem Size 3. 95% Confidence that actual side-lobe gain is less than model side-lobe gain.
Two-Level Two-Dimensional (Mean)	1. Main Beam Gain 2. Half-Power Beam Width 3. Dynamic Operation		1. Cull 2. Reducing Problem Size 3. 50% confidence that actual side-lobe gain is less than model side-lobe gain.
Four-Level Two-Dimensional	1. Main Beam Gain 2. Half-Power Beam Width		1. Cull 2. Prediction (limited)

FIGURE 17

SUMMARY OF ANTENNA MODELS

The use of detailed, three-dimensional patterns to predict EMC is not practical because an enormous amount of data is required to describe the radiation characteristics of an antenna and the fine structure of the patterns changes with frequency, range in the Fresnel zone, and site effects. The experimental data obtained during the study showed that the gain characteristics of a search radar antenna can be described by a Gaussion curve specified by a median gain and a standard deviation. A single Gaussian curve is a valid description of the gain characteristics of an antenna for all in-band frequencies and all ranges including the Fresnel zone. Mutual gain measurements (using two antennas, both rotating) have shown that the statistical distribution for mutual gain is also Gaussion with a median gain equal to the sum of the median gains of the individual antennas and a standard deviation equal to the square root of the sum of the squares of the individual standard deviations. With the parameters of transmitter power, frequency and distance between antennas, a probability distribution of received pulses can easily be determined for two interfering radars.

Antenna coupling representations most applicable to the aerospace cosite configurations on-board aircraft, etc., can be found in the University of Michigan report which was referenced in the L-band analysis discussion. The report presents detailed information on a wide variety of coupling situations involving two antennas. Most of the effort was on flush-mounted antennas due to this often specified requirement for airborne and aerospace vehicles.

In general, a good knowledge of antenna modelling exists but coupling data for aerospace antennas in various altitudes with respect to one another (for other than the cosite case) are not easily found. Additional measurements for this purpose should be made on antenna types representative of the state-of-the-art in satellite antennas as well as aircraft antennas.

3.2.2 Measured Data for EMC Analysis Purposes

3.2.2.1 The Department of Defense's Spectrum Signature Program

THE DOD HAS ASSEMBLED A DATA BASE OF MEASUREMENTS REPRESENTATIVE OF THE EMISSION AND RECEPTION CHARACTERISTICS OF MILITARY EQUIPMENTS

The DOD spectrum signature measurement program has been in existence for many years and a large collection of individual equipment signatures has been accumulated. The difficulty in acquiring access to this measured data presents a major problem in analyzing potential EMC problems in those frequency bands, shared by NASA and the U.S. military.

The successful operation of most military systems depends upon the use of information received through electromagnetic radiations. In order to predict the mutual interference effects of electronic equipments, the entire transmitter emission spectra needs to be known, as well as the susceptibility of receivers to signals having various frequencies, powers, and modulations that may exist in their operational environments. In order to obtain this type of information for representative military equipments the Department of Defense initiated in the early 60's the preparation of Signatures. This standard, revised several times since, establishes uniform measurement techniques that are applicable to RF transmitters and receivers with the goal of ensuring the compatibility of present and future systems. The data obtained from the measurements described in the standard are supposed to comprise a principal aid for predicting the performance of equipments in an operational electromagnetic environment. Several hundred radar and communication equipments have been measured and approved spectrum signature reports prepared. Unfortunately, many of those of most interest to NASA because of their operational frequency or power are presently unavailable to NASA because of their special nature.

The spectrum signatures in existence represent equipments operated by all branches of the U.S. military. Many of the Army equipment spectrum signatures were measured by contractor personnel at Fort Huachuca, Arizona. The Navy spectrum signatures were measured on-board ship, at training facilities or at the Navy NANEP facility at Patuxent, Maryland. The Air Force spectrum signatures were measured at production facilities, air bases and in some cases from a specially instrumented aircraft.

Over one-half of the existing radar spectrum signatures are classified either secret or confidential so that a specific need-to-know would have to be established by NASA to secure access to the reports. Most of the communications spectrum signatures are not classified but many are limited distribution documents which again acquire a special approval for release to NASA.

The high cost of obtaining a spectrum signature according to MIL-STD-449 has limited the number of different nomenclatured equipments measured. For the majority of equipment nomenclatures, only a single representative has been measured. The result is that statistical representations of measured data for most equipment types do not exist.

3.2.2.2 The ECAC External Support Program

SPECIAL MEASUREMENTS HAVE BEEN MADE BY THE MILITARY SERVICES FOR USE BY THE DOD's ELECTROMAGNETIC COMPATIBILITY ANALYSIS CENTER

The DOD ECAC External Support Program was made possible by the willingness of the individual services to contribute time, effort, funds and equipment to support specific measurement areas deemed by the ECAC to be important to the EMC modelling efforts.

The External Support Program has been essential to ECAC's effort to represent the various elements of an interference situation. For example, many Air Force compatibility problems involve the representation of antenna coupling on-board aircraft. Such a study was made by the University of Michigan on an Air Force contract and the results have been made available for ECAC use as well as to others via the Defense Documentation Center (DDC). Many of the most useful External Support tasks were accomplished by contractor personnel at the Army's Fort Huachuca. Measurements of communication transmitter spurious outputs with dummy loads and with antennas and measurements of receiver characteristics were made on several different serial numbers of a given type of equipment. These measured data are useful to the ECAC for modelling equipments.

At the present time, outside agencies are not given models developed by ECAC and they are used on a NASA compatibility problem submitted to and accepted by the ECAC. Although a panel of experts convened at ESD Hanscom Field to review the state-of-the-art in EMC several years ago included in their recommendations that ECAC should make available their receiver models, propagation models and their data base to the CIA, NSA, and NASA, this has not been accomplished for NASA to date.

3.2.2.3 The Electromagnetic Environmental Test Facility

THE ARMY HAS OPERATED A LARGE EMC ENVIRONMENTAL TEST FACILITY FOR YEARS AT FORT HUACHUCA, ARIZONA

A complete array of desired links and interfering transmitters was operated over miles of different types of terrain at communications frequencies normally used by the Army.

For many years contractor personnel have conducted large scale interference measurement tests using Army communications equipments at the Electromagnetic Environmental Test Facility (EMETF) in Arizona. The approach to interference detection and data analysis for the test system has been that no manual reduction of data is required. Interference is detected at the output of each receiver under test by making intelligibility tests using automatic equipment. Intelligibility levels appear at the output of the interference detection equipment and are punched into computer cards at each test site. The recorded results of the environmental tests for all receivers at the test site are then inserted into a computer with an environmental program which enables the printout of a list of potential interfering transmitters.

The test approach used at the EMETF allows the validation of theoretical solutions to the compatibility problems posed by various arrangements of transmitters, receivers, modulations, and frequency assignments. The results of this Army effort would be helpful in the design of any EMC validation tests.

In addition to the DOD spectrum signature program, the ECAC External Support Program and the Army's EMETF Measurement Program, considerable propagation measurements have been made by the United States Government's Environmental Science Services Administration at Boulder, Colorado and other propagation data will become available due to experiments planned by NASA to be conducted from ground and from satellite to earth and vice versa.

3.2.3 Environmental and Equipment Characteristics Data Bases

DATA FOR SPECTRUM MANAGEMENT AND EMC ANALYSIS PURPOSES

A survey of the available documentation relating to environmental and equipment characteristics data bases indicates that no single data file is adequate for NASA aerospace EMC analysis purposes but that the DOD/ECAC files come closest to meeting NASA's environmental data needs for equipments located within the continental U.S.

A data file for aerospace EMC analysis purposes must contain information regarding the location, operating agency, electronic and operational characteristics of environmental equipments. In addition to these very basic requirements, NASA must have worldwide environmental data and information regarding future installations of electronic equipments likely to cause mutual EMI problems. The requirement for worldwide data stems from the fact that satellites at synchronous and non-synchronous orbital altitudes can receive interference from sources dispersed over a wide geographical area at all points along the satellite orbit. Information regarding future installations of electronic equipments is critical because effective equipment frequency planning must precede actual operational implementation by as many as five years.

Table 6 summarizes the characteristics of the three major environmental files of U.S. located electronic equipments in existence today that are applicable for spectrum management, EMC analysis or both purposes. Table 7 allows a comparison between these environmental files based on the type and quantity of technical data contained in each of these files.

During the course of the survey it became apparent that

TABLE 6

CHARACTERISTICS OF MAJOR ELECTRONIC EQUIPMENT ENVIRONMENTAL FILES, U.S. EQUIPMENTS

ORGANIZATION	RADIO FREQUENCY FUNCTION	PURPOSE OF FILES	FILE ORIENTATION	BASIC FILE SIZE (RECORDS)	MAINTENANCE INTERVAL	STORAGE MEDIUM
ECAC	ADVISORY CAPACITY TO DOD	EMC ANALYSIS	GEOGRAPHICAL LOCATION/ EQUIPMENT TYPE	405,000	CONTINUOUS UPDATE-ANNUAL VERIFICATION	MAGNETIC TAPE
IRAC	USAGE AUTHORIZA-TION/ REGULATION (FEDERAL GOVERNMENT)	RADIO SPECTRUM MANAGEMENT	FREQUENCY/ GOVERNMENT AGENCY	113,000	MONTHLY	MAGNETIC TAPE
FCC	USAGE AUTHORIZA-TION/ REGULATION (NONFEDERAL GOVERNMENT)	RADIO SPECTRUM MANAGEMENT	SERVICE CATEGORY/ FREQUENCY	1,640,000	WEEKLY	MAGNETIC TAPE

TABLE 7

TYPE OF TECHNICAL DATA CONTAINED IN THE ECAC, IRAC AND FCC ENVIRONMENTAL FILES

TECHNICAL ITEM	AGENCY		
	ECAC	IRAC	FCC
Call Sign	x	x	x
Frequency	x	x	x
Class of Station (e.g., fixed, mobile, etc.)	x	x	x
Mobility Data			
Type	x		
Quantity	x		x
Area of Operation	x		x
Type of Equipment (transmitter, receiver)	x		
Equipment Characteristics	x		
Equipment Nomenclature	x		
Equipment Serial Number			
Major System to Which Equipment Belongs	x		
Equipment Operating Schedule	x		
Operating Time Restrictions	x	x	
Circuit			
Range (Path Length)			
Net Control Number	x		
DCS Trunk Designator	x		
Transmitter			
Location Name	x	x	x
Terrain Type	x		
Emission Type	x	x	x
Bandwidth	x	x	
Power	x	x	x
PW/PRF	x		
Antenna			
Coordinates	x	x	x
Elevation	x		x
Name/Type	x	x	
Dimensions (including Height, Structure)	x	x	x
Gain	x	x	
Azimuth	x	x	
Scanning Mode	x		
Beam Width	x		
Elevation Angle	x		
Polarization	x		
Receiver			
Location Name	x	x	
Required S/N		x	
Noise		x	
Antenna			
Coordinates	x	x	
Name/Type	x	x	
Dimensions	x	x	
Azimuth	x	x	
Gain	x	x	

Note: X indicates file contains annotated information there was a large area of duplication in the basic data maintained in the files of the respective organizations. It was also uncovered that there existed no standards among these agencies for the collection, coding, storage or processing of this data such that use of one agencies data by another would certainly be a technically cumbersome process. The major differences between the data in each of these files was directly relatable to the difference in administrative function performed by these agencies. The ECAC files were found to contain a large portion of that information contained in the IRAC and FCC data files although the reverse situation was not found to be true. The FCC and IRAC files were found to be basically of an administrative nature. That is, the data collected was used in the main to keep record of frequencies and their users. The FCC and IRAC data was also found to be lacking in regard to receiver information.

As stated previously, the three data files discussed contain data on U.S. located equipments. The ECAC files however, do contain a limited amount of environmental data external to the U.S., having collected data in Hawaii and on U.S. military forces in western Europe. The only other easily accessible data file containing information on equipments external to the U.S. is the International Frequency List of the International Telecommunication Union (ITU). The ITU file is largely an assignment list rather than a usage list. That is, there is no guarantee that those users appearing in the list are making use of the associated frequencies merely that these frequencies, often blocks of frequencies, have been assigned to this user. In this regard it is similar to the FCC and IRAC data files. The list is important in EMC analysis work in that it does represent official authorization information and even though its accuracy is questionable, it should not be ignored when evaluating frequency management problems concerning equipments external to the U.S. Table 8 presents the type of data available from the ITU Frequency Lists.

Up to this point, the discussion has centered on environmental data bases, that is files relating frequency use and equipment location. There is a second category of data files important in EMC analysis work which can supplement the data available from the four environmental files discussed. This type of file, sometimes called an "Equipment Nominal Characteristic File" contains a second level of detail, regarding the electronic characteristics of equipments, beyond that contained in the environmental files. For example, while the environmental file might only indicate a single operating frequency for a particular equipment, the nominal characteristic file would give the tuning range capability of that equipment. At present, the only known file of this type is that maintained by the DOD at their ECAC facility. This file contains approximately 25,000 general, receiver, transmitter and antenna records in magnetic tape, punched card and printout format. Table 9 illustrates the type of data contained in this file.

TABLE 8

TYPE OF DATA CONTAINED IN ITU FREQUENCY LIST

Data Entries in ITU Frequency List
Assigned frequency
Date of putting into use
Date of receipt of the notice by the I.F.R.B.
Call sign (Identification)
Name of the transmitting station
Country in which the transmitting station is located
Geographical co-ordinates of the transmitter site (longitude and latitude) in degrees and minutes
Locality(ies) or area(s) with which communication is established
Length of circuit
Class of station and nature of service
Class of emission, necessary bandwidth and description of transmission
Power
Azimuth of maximum radiation
Maximum hours of operation of the circuit to each locality or area
Megacycle order of the other frequencies normally utilized for the same circuit
Operating Administration or Company
Postal and telegraphic address of the Administration responsible for the station
Results of examination and investigations by the I.F.R.B.
Remarks related to the Finding by the I.F.R.B.

TABLE 11

SUMMARY OF SMALL COMPUTER AND DATA PLOTTER FACILITIES

Computer or Plotter	Cal. Comp. Plotter	1500 Computer	1401 Computer	Cal. Comp. Plotter	4020 Plotter
Installation	ERC(NASA)	ERC(NASA)	Harvard U.	Harvard U.	Houston(NASA)
Manufacturer	Cal. Comp. Products	UNIVAC	IBM	Cal. Comp. Products	Unknown
Hourly Rate	None	None	$30	$6	Unknown

3.3 NASA EMC Analysis Requirements

FOUR CAPABILITY DEVELOPMENT PROGRAMS

The analysis capabilities which are suitable and available for problem solving use have been identified. The capabilities that are not available or which have not been fully developed by others and which are required for aerospace EMC analysis are identified here.

The four critical areas identified as those specific capabilities that must be developed immediately to make possible the successful solution of a majority of EMC aerospace problems are, (1) Aerospace Receiver Modelling for Frequency Management Purposes, (2) Space Channel Characterization for Frequency Management Purposes, (3) An EMC Systems Analysis Tool for NASA Aerospace Frequency Management, and (4) Aerospace Cosite Frequency Engineering.

The first task under the recommended effort would result in models for present and planned NASA aerospace receiving systems operating in the presence of desired, undesired and noise signals and would predict their performance degradation in the presence of selected interference signals. It is recommended that threshold extension, PCM, and multiple access receiving systems be analyzed for vulnerability performance.

The second task under this effort would lead to the development of a channel model that will represent the earth-to-space, space-to-space and earth-to-space-to-earth communication links. This model should initially be developed for the NASA allocated microwave bands and should include considerations of basic spreading loss, refraction, diffraction, noise, multipath fading, and doppler spread.

The third task would result in the development of a frequency file of equipments and equipment nominal characteristic data for those systems sharing NASA frequency bands. In addition, this task should include the design and development of a computer program to perform a rapid cull on this file and to identify potential interference system nomenclatures.

The fourth and final task would result in the development of an aerospace cosite model that would assist aerospace vehicle program managers and alert them of potential radio frequency incompatibilities among the electronic and communication complements on-board satellites, space vehicles and high performance aircraft such as the SST V/STOL and V/TOL types.

3.3.1 Aerospace Receiver Modelling For Frequency Management Purposes

RECEIVER SUSCEPTIBILITY, A CRITICAL FACTOR IN EMC ANALYSIS

Ignoring the effects of the characteristic receivers, modems, decoders and signal post-processors on interference signals can lead to gross overestimates of the interference situation.

It is not uncommon in the engineering community to read about potential interference situations predicted solely on the basis of a "high" undesired-to-desired signal ratio existing at the terminals of a victim receiver. These types of analyses were adequate in the past when there existed essentially a linear relationship between input and output undesired-to-desired signal ratios and this quantity had a strong correlation with system performance. This situation was basically true for conventional AM and FM systems although not completely adequate for the FM case because of the presence of the limiter in FM receivers. Unfortunately, when these prediction methods are applied to today's and tomorrow's sophisticated receiving systems, the results are often erroneous. It is known for instance that spread spectrum systems can operate reliably at input signal-to-noise ratios in the neighborhood of -30 dB. Also, coding techniques exist (e.g., Reed-Solomon block codes and Galleger or Massey convolutional codes) that can correct multiple burst errors such as those that might occur as a result of strong pulse interference. Today's EMC analysis tools would incorrectly predict these interference situations.

Today, we are enjoying a modulation, modem and coding boom. That is, defense and space requirements for more reliable communications has led to the development and refinement of countless frequency and phase modulation classes; coded digital communications is becoming commonplace; multiple access, adaptive modems are here, and there is more to come. Yet, with the admittedly crowded spectrum conditions, no major attention has been focused on answering the question, "Will these receivers work in an environment that includes not only noise, multipath and fading, but also man-made noise and undesired signals". Most communication system designers will resoundedly answer that "it is the channel that most strongly influences the choice of modulation, coding, adaptivity, etc., in the design of a communication link". But a channel model that ignores the system degradation effects of undesired signals or a prediction method that applies "state of the art" analysis techniques to noise and semi-qualitative analyses to undesired signals are bound to lead to gross underestimates or overestimates of the interference situations.

To attempt to develop receiver models for every conceivable modem, code and signal processing scheme NASA is using or planning to use is rather quixotic and would soon be found to be futile. Developing massive, generalized receiver models is also impractical, as experience has shown that usually generalized models are so comprised by attempts to have them represent a wide range of equipments, that they rarely fit any specific case very well.

The approach that is recommended is one of selecting a few of the most prominent receiver system techniques already in use and projected for future use by NASA and analyzing in depth, the susceptibility potential of these systems. Specifically, the generic receiver categories that should be analyzed are:

1. Threshold Extension Receivers
2. PCM Telemetry Receivers

3. Multiple Access Receivers

The first category of receiving systems includes both phase-lock loop and FM with feedback techniques. The PCM class is expected to consist of PCM-AM, and PCM-PM subclasses. The third class of receivers will include frequency division, time division, code division and spread spectrum multiple access techniques as well as the various hybrid combinations of these modulation schemes.

Specifically, it is recommended that a research program be initiated that would:

1. Select the modulation classes of undesired signals to be played against the aerospace receiver configurations selected. This should be done by examining the prominent modulations of environmental equipments sharing the NASA allocated frequency bands or having harmonic frequencies in these bands, that have a strong present or future potential for interference. It is anticipated that this class should as a minimum consist of at least CW and pulse interference waveforms as well as Gaussian noise.

2. Model mathematically the critical subsystems of each receiver configuration selected for analysis. This should include models for mixers, filters, phase detectors, decision devices, etc. In every case, the modelled subsystems should have a reasonable likeness to existing hardware.

3. Utilizing the desired signal, undesired signal and noise waveforms established, and the receiver models selected, process mathematically these signals through the simulated receivers and arrive at predictions of susceptibility potential. The susceptibility potential for each receiving system should be expressed not only in terms of the amplitude and waveform characteristics of the undesired signal, but also in terms of the frequency seperation between

desired and undesired signals.

4. Derive the relationships between receiver system performance and such factors as input signal-to-interference and signal-to-noise ratios. Receiver performance should be expressed in a form most applicable to the system being analyzed. For example, phase-lock-loop performance may relate signal-to-interference ratio for specific noise ratios to such factors as (1) the RMS phase error, (2) the probability of break-lock, and (3) the mean time to break lock.

3.3.2 Space Channel Characterization For Frequency Management Purposes

A FREE SPACE PROPAGATION MODEL IS NOT ADEQUATE

A program is urgently needed at this time which will consider both theoretically and experimentally, the formulation of a channel model that will represent earth-to-space, space-to-space and earth-to-space-to-earth communication links operating in the presence of interference signals

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The term channel, as applied here, represents the entire environment existing between a transmitting and receiving antenna in a space communication system. It includes considerations of the basic wave spreading loss (i.e., the loss due to the expanding wave-front of a propagating electromagnetic wave), additional propagation path losses introduced by terrain, weather and atmospheric anomalies, additive effects such as receiver noise, atmospheric noise, noise from precipitation, blowing snow or dust, and corona, extraterrestrial thermal noise originating from the various galaxies, the sun, the moon, and the planets and man-made noises. In addition to additive effects, the channel introduces multiplicative effects which result in possible multipath and fading of signals. All of these effects vary widely, depending strongly upon the frequency of the transmitted radio wave.

At present, most models used to represent the space channel have been based on free-space propagation or, at most, include some elementary considerations of dispersion. This is due in large part to the lack of experimental data needed to help characterize the space channel. The seriousness of this present data shortage hinges on the important question of how closely the space communication link approximates the free-space conditions. There are two schools of thought on this question at the present time. One group is confident that the link will be essentially like free space, at least in the frequency range from 0.3 to 8 GHz. This view is supported by experimental observations that have been obtained on signals from satellites in low-altitude orbits. The other group, influenced by occasional observations of signal fading and other distrubances, and especially by some of the signal characteristics from Pioneer V, is much less confident that there is no need for concern about propagation anomalies. From a certain point of view, the free-space model is surely incorrect. Even in the absence of interplanetary effects, the signals must pass through or be scattered by the ionosphere and the troposphere, both of which are subject to considerable flucuation in electrical transfer characteristics, and the signals will therefore be distorted somewhat. The actual question is then, is the effect important? For analog space communication systems these effects result in waveform distortion or reduction in articulation index as in the case of voice-analog systems. If these effects are severe, the degradation of analog system performance takes the form of serious intermodulation distortion, rendering these systems nonacceptable for reliable communications. For digital communication systems, these fading and multipath channel perturbations also result in waveform distortion leading to possible intersymbol interference and therefore high bit-error rates. For low digit rates these channel effects may be of little interest. However, as the required transmission rates extend into the megabit range, these effects become critical and of dominant importance in the channel characterization effort.

Specifically, it is recommended that a program be initiated that would:

1. Conduct a thorough and exhaustive search for exper-

imental data and theoretical models for the earth-to-space, space-to-space and earth-to-space-to-earth communication channel for the microwave band of frequencies.

2. Utilize the experimental and theoretical data to mathematically model the space communication channel. The model should be a stochastic representative of the space channel for each of the NASA assigned frequency bands and should further reflect the differences between atmospheric anomalies from band-to-band. The basic path loss data for each appropriate frequency band should be expressed as a probability distribution function, that is, the probability that a given signal power level will not be exceeded versus that power level. The path loss distribution functions should be prepared for each applicable mode of signal propagation, for example, (1) knife edge defraction; (2) tropospheric scatter; (3) precipitation scatter, etc. The channel noise models should be expressed as random processes with each random variable of the process having its probability law and range of parameters specified as functions of such factors as season, time of day, geographic location, frequency, receiver bandwidth, etc. The channel multiplicative effects such as fading and multipath should be reflected in the channel model as complex time and frequency channel correlation functions. These functions find wide use in the computation of error rates for digital signals, and from them, such factors can be obtained. Wherever possible measured data should be used to construct the channel submodels. In the absence of this data, theoretical or simulated models should be employed. This phase of the study should also point out the limitations in measured and theoretical models and should make specific recommendations to remove these limitations.

3. Automate, the space channel model such that, given a

set of user input parameters such as transmitted signal level, separation distance, receiver bandwidth, frequency, spacecraft or ground-link location, time of day, season, etc., the program will select the appropriate submodels, perform the necessary computations using these submodels and finally predict such data as, (1) the median or mean path loss, (2) the average noise power at the receiver terminals, and (3) the multipath and doppler spread factors for the specific link.

3.3.3 An EMC Systems Analysis Tool For NASA Aerospace Frequency Management

A COMPUTER PROGRAM SIMPLIFIES IDENTIFICATION OF INTERFERENCE NOMENCLATURES

An objective investigation of the applicability and accessibility of EMC Systems Analysis tools in existance today has led to recommendation for the development of a new streamlined and economical NASA oriented EMC systems analysis tool.

A great majority of the existing analysis programs depend upon large environmental files of electronic systems. These files are played against a few equipments to determine the potential for interference. This initial process, as stated previously, is called a "cull". The "cull" programs (e.g., RADC's IPP-1, DOD's MSS-2) are massive, extremely generalized and require very large data bases. A thorough study of the existing programs has led to the evolvement of an EMC/Frequency Management problem solving philosophy that is superior in most ways to the existing one. This more logical and economical process would consist of, (1) performing an extremely rapid and coarse cull on a frequency and nomenclature basis versus an environmental file basis to determine whether or not a problem really exists at all, (2) determining what characteristics a potential environment equipment must possess in order to cause interference or have interference caused by a NASA electronic system of interest, (3) ferreting out those equipments by nomenclature, that exceed a series of equipment characteristic thresholds established in step 2 and finally, (4) requesting from those agencies (e.g., DOD, ITU, FCC, IRAC, etc.) the locations and operating agencies of equipments in their files of the identified nomenclatures. This last step represents a realistic request of these agencies, in that by requesting a small amount of basic information, their response is more likely to be positive and timely.

The two basic elements of the preferred analysis process described are, (1) a frequency file of equipments containing certain equipment nominal characteristics, and (2) a process by which, given some frequency and equipment characteristic constraints, this file may be used in the rapid cull and nomenclature ferreting processes described above. Specifically, it is recommended that a program be initiated that would:

(1) Develop a frequency file of equipments and equipment nominal characteristic data for those systems sharing NASA frequency bands or having some harmonic relation to these bands. This file could be developed from data readily available from the DOD, FCC, IRAC, ITU and any other agencies that may make their equipment files available. The file should be prepared in magnetic tape format compatible with NASA/ERC's IBM 7094 II computer facility.

(2) Design and develop a computer program that utilizes the developed data file to perform a rapid search process for equipment nomenclatures meeting a number of user specified constraints, such as frequency, effective radiated power, modulation, receiver sensitivity, etc., and that formats and prints the selected nomenclatures together with other equipment data of interest.

The EMC Systems Analysis tool described above is designed to circumvent the problems associated with existing programs generated by their strong reliance on huge environmental data files. These data files contain detailed information on a large number of environmental systems which must be constantly updated and checked for accuracy, all at a high cost. Since these "cull" programs are generalized, their working philosophy is to minimize the chances of overlooking a potential environmental interference source or victim. Unfortunately, this process, in its attempt to be "fail-safe" requires successive computer or manual culls, all extremely wasteful of both man-power and dollars, before a sufficiently small number of these systems are isolated, allowing a more detailed analysis.

If objections to the use of existing EMC analysis programs were based strictly on their lack of processing efficiency and the high cost of environmental file development and upkeep, a closer inspection would be required to determine the cost-effectiveness of using directly or modifying the existing programs versus developing a new EMC capability. The over-bearing argument against their use is that they require an environmental file for their operation. It has already been established during the process of the study that the acquisition of these environmental files for use by NASA in their EMC/Frequency Management Program will be an extremely difficult, if not impossible process. The presence of special "need-to-know", proprietary and sensitive military data in these files all contribute to this inaccessibility, at least for the present.

In summary the Systems Analysis tool recommended for development has the advantages of speed and adaptibility without complete reliance on huge environmental files for initial "cull" processing.

3.3.4 Aerospace Cosite Frequency Engineering

A FREQUENCY PLAN FOR CO-LOCATED AEROSPACE EQUIPMENTS

An aerospace cosite or on-board frequency engineering model must consider the important emission, coupling and vulnerability mechanisms which can occur in a satellite, space vehicle or high performance aircraft. Serious consideration given to the frequency engineering of co-located equipments on a given aircraft or satellite is of critical importance and can avoid mission failures caused by intermodulation, cross modulation, spurious responses, receiver desensitization and other undesired signal effects.

Most aerospace systems, such as satellites bearing a variety of earth's sensors, will consist of many different equipments operating at various radio frequencies. The objective of an aerospace cosite frequency engineering model is to predict at the earliest possible date any potential equipment incompatibilities that may exist between members of the satellite, space vehicle or high performance aircraft equipment complement. This model must be structured such that it will optimize the probability of the compatible operation of all of the equipments on-board. The Aerospace Cosite Frequency Engineering Program could be structured in a number of subtasks.

The first of these tasks titled "Frequency Engineering" should develop that portion of the cosite model that will enable the prediction of frequency interactions between equipments. The model should be capable of predicting co-channel, adjacent channel, intermodulation, cross modulation and spurious response frequencies. This frequency engineering task should enable the construction of a mutual interference chart for each co-located equipment that should, at a glance, alert system planners to any potential interference problems. A mutual interference chart (see Section 3.2.1.1) could identify those portions of an on-board equipments tuning range which are unusable due to undesired signals and hence could point out those regions within this tuning band which are suitable for interference free operation.

The second sub-task under aerospace cosite frequency engineering is entitled, "Receiver Desensitization Prediction". The modelling of receiver desensitization due to relatively high power inputs at frequencies within the RF band pass of the receiver should be done using empirical data. The data for such an approach is contained in the Department of Defense's Spectrum Signature Reports which are available to NASA.

The third task in this program is entitled, "Antenna Couplings Studies". The result of this study should enable the prediction of antenna coupling between co-located equipments such as those that could be located on the SST V/STOL aircraft or NIMBUS-E satellite.

The final sub-task in this program is titled, "Spurious Output Prediction". It is well known that active devices in the vicinity of sensitive receivers can transmit spurious outputs in addition to desired fundamental outputs that can cause serious interference problems. The most prominent spurious outputs are harmonics of the fundamental output. These emissions will be considered along with harmonics of any local oscillator which may have been used in the generation of the transmitted signal. This portion of the model should be developed from empirical data based on measurements which have been made on a wide variety of equipments applicable to this study.

In summary, it is recommended that this family of models, which together form the Aerospace Cosite Frequency Engineering Model be developed. This model could provide aerospace system planners with a valuable tool for the prediction of on-board incompatibilities due to interference and should point out the frequency engineering options available to minimize these problems.

3.4 NASA EMC Measured Data Requirements

MEASURED DATA, PROPERLY TAKEN, REPRESENTS THE MOST ACCURATE AND USEFUL INDICATION OF A SYSTEM'S PERFORMANCE

The most comprehensive data base of electronic equipments and their measured characteristics, suitable for EMC analysis work has been assembled by the DOD. It is primarily limited to equipments located within the continental United States. The information in this data base is not easily accessible to a non-military agency like NASA.

It would be impractical to suggest that NASA undertake a measurement program like the "Spectrum Signature Data Program" conducted by the DOD to obtain information concerning the electronic characteristics of environmental equipments. Although much of the required data is difficult to obtain, it has been collected, and would, both from a technical and cost basis be impossible to reproduce. It is practical, however that NASA undertake a measurement program specifically designed to develop a special data base for use in aerospace EMC problems. This data base could contain the statistical description of the man-made radio noise environment at orbital altitudes on a world-wide basis.

Before initiating a research program to obtain this data it is suggested that a determination be made of the feasibility of obtaining meaningful man-made radio frequency noise at orbital altitudes. Once the feasibility is established, the detailed design and construction of an experiment to provide the measured data should be accomplished and the experiment performed. Finally the data acquired must be analyzed and mathematical models appropriate for use by communications system designers and electromagnetic compatibility engineers developed.

Without this noise data, the communications system designer is either forced to neglect the impact of this type of noise on his system or if aware of it potential significance, utilize makeshift analytical tools in an attempt to evaluate its relation to such critical design decisions as choice of frequency band, class of error correcting code, modem type, signal waveform design, data rates, transmitted power and antenna directivity.

The EMC engineer, responsible for providing frequency allocation and assignment guidance to system planners, is also constrained by this lack of data and turns invariably to the classical analytical approach used to predict interference to ground based systems only to find these techniques cumbersome and not easily adaptable to a large class of satellite vulnerability problems.

A theoretical approach to the problem of prediction of the effect of man-made noise and signals on aerospace communication systems suffers from a number of related deficiencies. The amplitude, phase, and time characterization of undesired signals at a satellite location, for example, are all related to the following considerations:

1. Existing data bases of electronic emitters and their characteristics are limited to equipments located in the continental United States. Therefore, signal prediction at orbital altitudes do not include contributions from other than U. S. based equipments. The DOD's data base, which is the only existing information bank of its size and type in existence is not easily accessible to a nonmilitary agency like NASA.

2. There is no method for analytically combining the large number of man-made radio noise signals arriving at the satellite location. Therefore, while individual contributions from ground based systems may be negligible, the combined signal densities could cause considerable system degradation.

3. There is not available a data file of the operational duty cycle or on-off time statistics of electronic emitters. Without this data, such information as burst lengths, time between bursts and impulse rates within bursts, so necessary to the communication system designer and compatibility engineer, can not be predicted, assuming of course, that a suitable method were available for combining the duty cycle statistics of multiple emitters.

A program designed to meet the man-made noise requirements of both satellite communication system designers and EMC engineers should consist of the following major efforts.

1. A thorough and exhaustive literature review designed to uncover information concerning existing man-made radio noise data, mathematical noise models for other noise types that may be applicable to this problem and the prediction of noise effects on satellite sensors and communication receivers.

2. A determination of the noise statistics required to predict the performance of satellite communication receivers and sensors. Existing man-made noise measurements performed on the ground and from airborne platforms consist almost in total of noise power recordings. This type of data finds wide use in the evaluation of analog communication systems where the signal-to-noise power ratio is generally the most critical parameter. In digital communication systems, and particularly coded communication systems, it is imperative that the amplitude, phase and time duration statistics of the noise on a per frequency basis be available. With this data, the degradation parameter for digital systems, that is, the digit error rate or probability of bit errors, character errors or message errors can be predicted. This data is also a requirement in guiding the specification of the required

random or burst error correcting properties of codes, the choice of modem modulation, data rates, and transmitted power.

3. The development of a measurement plan for the collection of man-made noise statistics at orbital altitudes. Since as a general matter, noise not in the category of wide sense stationary Gaussian noise requires more than just a few simple parameters, or a single function for its specification, the measurement scheme must reflect a compromise between the noise statistics required to evaluate system performance, the statistics required to specify the man-made noise random process and practical considerations of the cost and complexity of the experiment. While it may prove necessary initially to measure the detailed structure of man-made noise, experience may quickly reveal enough about man-made noise to permit approximation of some of the required noise statistics from selected measurements. As a minimum, it is anticipated that the measured parameters should include the envelope, phase and burst random variables of man-made noise as related to satellite location, time of day, frequency, receiver bandwidth, and satellite antenna orientation and directivity. The measurement plan should also provide the rationale behind whatever signal sampling and statistical data sampling criteria should be employed in gathering the noise information. The design of an instrumentation package in concert with present NASA programs and existing or readily available measurement, recording and telemetry equipments should also be included in the measurement plan.

4. The development of a mathematical man-made noise model that includes as a minimum, envelope amplitude, RF phase and burst duration variables and accounts for the variation of satellite location, time of day, frequency,

receiver bandwidth and antenna parameters.

5. The development of mathematical models for amplitude limiting devices used in satellite receivers. These models should be applied to the determination of the output man-made noise statistics after amplitude limiting.

6. The development of a procedure for the prediction of satellite digital modem performance in terms of digit or character error rates as a function of system input signal-to-noise ratios for several satellite modem configurations operating in man-made noise, receiver noise and if applicable atmospheric noise as well as multipath and signal fading.

A nominal characteristics file for all of the NASA equipments is of great value in addressing aerospace EMC problems. However, there is no substitute for the measured data which can be obtained by making even limited spectrum signature type measurements on the NASA equipments. Such parameters as transmitter spurious outputs, emission bandwidths, harmonics, and receiver RF characteristics and spurious responses are invaluable for the determination of potential EMC problems. The measurement of the nondesign frequency emissions and responses of aerospace equipments should be subjected to a series of measurements to determine the nature of the nondesign characteristics.

In summary, the levels of man-made noise (including signals) at orbital altitudes for certain frequency bands of prime interest to NASA and the measured characteristics or spectrum signatures of aerospace radio frequency equipments both represent important measured data requirements to support a NASA/EMC program.

3.5 NASA EMC Environmental and Equipment Characteristics Data Requirements

DATA AND DATA MANAGEMENT

NASA will have to depend on support from the DOD ECAC facility for a large portion of their data base until such time as a special NASA Frequency Management/EMC Analysis information bank is created or a national data base easily accessible by all qualified users is established.

The establishment of an effective data base requires not only the identification of data requirements, location of data sources and the collection of these data, but also the establishment of techniques for updating the information, providing quality control of the data, that is filling in missing data and identifying suspect data, and most importantly, facilitating access to this information. These processes combine to form a data management system and without this system the data base cannot be utilized to its maximum capacity.

It has been pointed out in this report that the ECAC data base, both the Environmental File and Equipment Nominal Characteristics File are the most comprehensive data files of their kind in existence today. It has also been suggested, based on experience gained on a similar NASA study, that this data will not be made available to NASA, at least not in its entirety, also that NASA service requests to the ECAC will have to be carefully structured to make possible reasonably timely responses. With both of these facts in mind, it is recommended that,

1. NASA make a formal request to the ECAC for selected portions of the Equipment Nominal Characteristics Data File that contain equipments sharing frequency bands with NASA

equipments. The data request should also consider harmonic frequency sharing as well as co-band and adjacent band sharing. To overcome the sensitive security, need-to-know and proprietary data problems, NASA could suggest to the ECAC that all "clear" identification data, such as nomenclature, be suppressed from the data given to NASA. NASA could then use this data, as suggested in Section 3.7, and then, only after identifying potential interference problems, request from the ECAC, the additional identification, location, operating agency and other data.

2. NASA investigate the feasibility of acquiring world-wide data from such sources as intelligence services and military logistics groups. At a minimum, the ITU Frequency List data in the appropriate frequency bands should be assimilated in a convenient format into the NASA data files. Attempts should be made to acquire from the ITU, additional data (e.g., equipment nomenclature, operating frequency) for those equipments identified. Rules should also be established for filling in missing data, even if it means using "worst case" estimates.

3. NASA acquire data on common-carrier microwave radio relay equipments operating in the shared 4 and 6 GHz bands. This data should not only be of a characteristic nature, such as the typical antenna pattern for relay equipments, but should include actual location data, link frequencies, antenna pointing angles, terrain profiles in the neighborhood of these sites, etc.

4. NASA establish a data base of noise, both natural and man-made at orbital altitudes. The data should be recorded continuously and should consist of more than mere noise power recordings. The data should reflect the sensitivity of the noise and its statistics (e.g., amplitude

and phase distribution, burst length and duration distribution, second movement, etc.) to such factors as geography, time of day, season, bandwidth, frequency, etc.

3.6 Data Processing Requirements and Availability for Use in Developing a NASA EMC Analysis Capability

3.6.1 Data Processing Requirements

3.6.1.1 Digital Processors

DIGITAL COMPUTERS ARE PRESENTLY USED FOR EMC FILE STORAGE, SORTING AND RETRIEVAL AND FOR THE COMPUTATIONS INVOLVED IN AN INTERFERENCE PREDICTION

Digital computers are required for the thousands of computations involved in an EMC analysis involving even a small environment of emitters and receivers. A digital computer can in minutes, make the hundreds of couplet computations that would otherwise take weeks of manual computation.

The use of digital computers for EMC analysis has been well received, and is generally regarded as the accepted procedure for large numbers of emitters and receivers. One of the major uses of computers in the past has been the storing of large files of information relating to equipment characteristics and their physical environments. Usually the practice has been to store nominal equipment characteristics and environmental data on magnetic tape so that the data could be retrieved easily and in turn be used with mathematical models. The models simulate the physical aspects of the equipment in a true environmental situation. There are problems inherent in computer oriented studies wherein a large data file must be made accessible before meaningful analyses can be attempted. Analog and analog/digital hybrid computers are also important in the solution of specific interference problems wherein a rather limited number of arguments or variables are used to define or simulate the actual electromagnetic devices under investigation and they are discussed in Section 3.7.1.2.

One of the most difficult problems associated with a computerized analysis of interference problems is the need to have available to the computer program simulating the real world environment all the necessary inputs associated with the equipment to be studied. Since it is impossible to predict with any degree of certainty where future interference problems may be, i.e., with regards to either geographic location and/or type of equipment, it is imperative that a library containing environmental data, and equipment characteristics be constructed and be made available to a large scale computer. Any data base must be verified for accuracy, and checked for possible redundencies and errors. This type of error checking which does not involve firm and fast rules is not particularly suited for computerization and as a consequence is usually handled more efficiently by human beings. The computer program to generate an updated environmental magnetic tape file is a rather elaborate program which must take new data and construct environmental records properly placed amongst the existing records.

The files of the ECAC represent the most comprehensive effort to establish a data base consisting of environmental files and equipment characteristics files. The amount of surveyed information presently stored in the E-file (Environmental File) (which is their primary data file) approaches <u>100 million</u> characters. It should be apparent that it is neither necessary nor economically feasible for NASA to duplicate the efforts being performed by ECAC. The most direct approach and the least expensive one, is to translate the existing file which is in Univac 1108 internal code, to any other computer's internal code as designated by NASA. At present the best computer installation available for this translation process, and any other parallel computer process that may be required, is the 7094 II at ERC.

Assuming the problem of obtaining the environmental and equipment characteristics files is solved, i.e., they are made available to NASA either by ECAC or by any other government agency, there remains the problem of achieving the best use of this information. It is apparent that if "n" records are to be accessed from the data base as required input to a NASA analytical or statistical survey computer program, the E-File must be queried, a record at a time in sequential fashion, until either the entire E-File is exhausted or until all "n" queries are satisfied. The time it takes to perform this type of sequential processing of the file depends on the number of tape reels involved and also upon the type of interrogation being performed on the file. Usually, it is necessary in most data retrieval problems with files on magnetic tape, to start at one end of the file and work sequentially down toward the other end. By proper file organization it is feasible in most cases to eliminate from the search major portions of the file and thus decrease the overall processing time. For example, let us assume that instead of only one E-File on magnetic tape, the records of which are in no particular order, we had two additional E-Files each sorted using a two-word key, the first two-word key being frequency, power, in that order, and the second two-word key being power, frequency, in that order. When making reference to these files we will designate them as A (random), B (frequency-power) and C (power-frequency) files, respectively. If the job at hand is to determine the number or location of equipments in the file emitting within a certain frequency range and also greater than or equal to a certain power level, then it is obvious that file (B) is the most advantageous file to use.

It is apparent that a file must be organized, with full attention directed toward the type of analysis to be performed. An accepted means of holding large files of data which usually represents an improvement over magnetic tape consist of magnetic disc or magnetic drum storage. Access to any given disc/drum can be gained by moving the read/write head mechanism to the desired tract at high speed, without reading the intervening data. This is fast compared to magnetic tape access time, even when data read rates are comparable. (Read rates on drum are usually (30-50)% faster than magnetic tape).

Complex systems to be simulated require a team of different types of specialists to work simultaneously on the system design. A general simulation language like SIMSCRIPT (developed by the Rand Corporation, and in use since 1963) should be part of the background and training of the systems engineers developing the computer models of the interference studies since it will reduce the time from the inception phase, to the computer running phase.

Some of the major advantages of using SIMSCRIPT in simulation environment are as follows:

(1) Computers of many manufacturers have SIMSCRIPT compilers.

(2) Users other than the initial programmer can follow SIMSCRIPT models that are carefully structured and documented.

(3) Mathematical capability is virtually unlimited, since other programming languages such as FORTRAN IV can be called by the model as needed.

(4) Pseudodate (the simulated time of an event) can be introduced, since pseudorandom number sources are available. Graphical relationships can be used to structure data.

Some of the major disadvantages using SIMSCRIPT are as follows:

(1) SIMSCRIPT has a limitation of the size of model which can be run on available computers. Since greater detail means considerably more effort, there is less tendency to over-detail the problem in SIMSCRIPT.

(2) Documentation capability is very much up to the individual. Since actions are not obvious without documentation, there must be considerable effort to document the model if the system designer or anyone else is going to use it at a later date.

(3) Statistics during and after the running of the model have to be intentionally collected by the user. He can use almost anything but he has to know what it is called, where it is located, and how to get it.

(4) Debugging aids are limited, since the model structure is developed by the system designer rather than by a prescribed structure. This lack of structure can make debugging a time consuming and difficult process.

(5) Graphical presentation can be added by the user, but outside of a flexible report generator the input and output have to be programmed in detail for either display or presentation of relationships.

In order to develop a NASA EMC Analysis Capability without undue delay a FORTRAN IV compiler system must be made available to its systems analysts. Since almost all the work to date; in propagation prediction, in algorithm procedures used in the allocation of frequencies, in varying interference prediction modelling exercises; has been written in FORTRAN II or FORTRAN IV, it is almost mandatory that NASA secure a computer system that can readily accept FORTRAN as written for several manufacturer's machines.

Another important adjunct to FORTRAN is BEEF (Business and Engineering Enriched Fortran) which is considered a necessary tool to be used in the character manipulation of those fields of the environmental or equipment characteristics files requiring special attention (some fields will be a portion of a fixed word length). There are several pseudo instructions or subroutines that allow for character manipulation within a string and thus BEEF facilitates a greater enhancement of the data processing aspect of FORTRAN, which is primarily a scientific processor.

One final software package which is usually considered a necessity whenever large files are to be used, is a generalized file handler. A typical file handler will perform the following major file functions automatically for the programmer; open the file, fetch fields of a specific record of the file, close the file, perform check sums, perform checking on hardware and indicate hardware malfunction, write label and sentinel blocks, plus many other functions too numerous to mention.

In addition to the three major software packages described above required by the programmer analyst, a higher order simulation language, similar to SIMSCRIPT would be a useful tool to the engineer analyst engaged in interference prediction modelling.

Also, special mathematical subroutines like the evaluation of Fresnel Integrals; Hankel Functions; Fast Fourier Transforms; and general integration procedures would be extremely useful in the development of an EMC capability.

3.6.1.2 Analog and Hybrid Processors

ANALOG DEVICES ARE SUITED FOR LIMITED ACCURACY DESIGN STUDIES OF DYNAMIC SYSTEMS

The use of analog computers for EMC studies has not been widespread but some successful applications have been documented. The EMC engineer should consider the uses of both analog and hybrid processors for aerospace compatibility studies.

As with all calculating machines, the basic elements for an analog computer are:

(1) input devices,

(2) devices that perform the arithmetic and logical operations, and

(3) output devices.

The input devices to analog computers are not as sophisticated as that required by digital computers since the data are not voluminous. The basic reason is that the implied accuracy of analog computers does not warrant an elaborate data base. However, many analog devices will have magnetic tape input units which feed electrical voltages to the central computing device which is composed of operational amplifiers and resistors or capacitors. Hybrid computers as the name implies will usually consist of a digital interface with some analog device. The input signals may be completely controlled by a digital device thus allowing for arbitrary voltage inputs. Because of its memory and instruction capabilities a small digital computer can be used since the intended application of the analog device can be varied by interchanging one set of program instructions with another set. There are other analog computers that have both digital input and output devices. This is a very common occurrence in installations where digital computers predominate, since very often output from these systems will drive an analog computer.

The output from analog computers is usually taken in the form of an x-y graph made by a graph plotter, or in digital form by using an analog-to-digital converter. Visual displays on a cathode ray tube are also used for outputing analog computer information.

The analog computer is especially suited for limited accuracy design studies of dynamic systems, such as exemplified by a system of transmitters and receivers operating in a constantly changing environment. Parameters such as gains, bandwidths, center frequencies, power levels, etc., as well as initial conditions and forcing functions can be rather simply varied while the problem solution is in progress.

The use of analog computers in EMC studies has had some strong advocates in the past. Perhaps the best known computer simulation facility completely dedicated to simulation studies is the GEESE system (A General Electric Electronic System Evaluator). The cost of analog computations, and for that matter simulation, increases in an almost a logarithmic scale as the size of the problem or the required precision increases. Nevertheless, the researcher should not forget the fact that analog simulation has provided a major service to the solution of technological and scientific problems.

3.6.2 Data Processing Availability

A SUMMARY OF THE COMPUTER CAPABILITIES AVAILABLE TO NASA

This section indicates the major computer facilities that will be available to NASA/ERC and summarizes the major software packages that are also included.

A FORTRAN IV compiler is available at each of the installations which are presently engaged in supplying computer services for NASA personnel. A summary of the capabilities of the computer facilities either presently available or expected to be available by January 1, 1969 is presented in Tables 10 and 11.

It should be noted that all of the available installations that have 3rd generation computers have the desired software packages recommended as necessary requirements in the development of a NASA EMC Analysis Capability. The 7094 II facility at ERC (a second generation system) is handicapped because of its lack of character movement routines. Special emphasis should be placed in these two problem areas so that a swift and suitable solution can be accommodated. It is very likely that character movement routines are available from some other 7094 user or are obtainable through SHARE (IBM User's Organization).

Although the present survey of computer facilities emphasizes the availability of digital computers which would absorb the major thrust of any EMC analysis studies there was no implied intention of disregarding the availability of analog and hybrid systems. These systems which usually are designed to perform special functions and solve special problems originating from within a captive group of users, are much more difficult to locate because they are seldom open to scientists outside of their own organization and group.

TABLE 10

SUMMARY OF MAJOR COMPUTER FAC[illegible]LITY CAPABILITIES

COMPUTER	7094 MOD I	7094 MOD II	360 MOD 50	1108	6600
Installation	Harvard U.	ERC (NASA)	Harvard	Houston	Langley
Manufacturer	IBM	IBM	IBM	UNIVAC	CDC
Normal Usage	On Site	On Site	On Site	Remote	Remote
Hourly Rate, Central Computer time	$205	None	$100	$155	$200
Fortran Compiler	Yes	Yes	Yes	Yes	Yes
Beef Character Movement	No	No	Yes	Yes	Yes
File Handler Input-Output	No	No	Unknown	Yes	Unknown
SIMSCRIPT Simulator Language	No	No	Yes	Yes	Yes
Special Math. Routines	Yes	Yes	Yes	Yes	Yes

TABLE 11

SUMMARY OF SMALL COMPUTER AND DATA PLOTTER FACILITIES

Computer or Plotter	Cal. Comp. Plotter	1500 Computer	1401 Computer	Cal. Comp. Plotter	4020 Plotter
Installation	ERC(NASA)	ERC(NASA)	Harvard U.	Harvard U.	Houston(NASA)
Manufacturer	Cal. Comp. Products	UNIVAC	IBM	Cal. Comp. Products	Unknown
Hourly Rate	None	None	$30	$6	Unknown

It would be worthwhile for ERC to investigate the availibility of an analog or hybrid computer that could be used on a continuing basis for simulation and parameter optimization studies relating to electromagnetic analysis.

There is very little difficulty expected to arise as a consequence of using the ERC computer facility. A special demonstration computer program which evaluated distance-frequency criteria in an environmental situation, was programmed, key punched, and checked out on the ERC 7094 II computer, using the complete facility, i.e., both the Central Computer and its associated peripheral devices. The coordination between the computer services division and other divisions within ERC is excellent as evidenced by the smooth handling and successful completion of the demonstration program referred to above.

3.7 Three Additional Elements in Developing a NASA EMC/Frequency Management Capability

STANDARDS IMPROVEMENT, HANDBOOKS, FREQUENCY MANAGEMENT

By itself aerospace EMC research can only serve as a technical basis. It cannot implement or enforce improved equipment performance standards or encourage good design practices. It also cannot disseminate EMC information or educate NASA engineers, program managers and frequency planners or assist directly in solving the day-to-day EMC related problems that arise.

Previous sections of this report have discussed those research areas that should be undertaken in order to provide NASA with a capability to solve some of their current and anticipated EMI problems. This section discusses three additional efforts that should also be given special attention to assure that the direction and results of EMC research are properly guided and maximally beneficial. These areas of concern are:

(1) Improvement of existing EMC standards and specifications,

(2) Information dissemination, education, analysis and design guidance via a series of handbooks, and

(3) A frequency management program responsive to current NASA EMC problems and capable of projecting and providing for NASA frequency requirements in the 1970's.

3.7.1 A First Step in the Improvement of Existing Aerospace Related EMC Standards and Specifications

IMPROVED STANDARDS CAN LEAD TO MORE EFFECTIVE SPECTRUM UTILIZATION

A program is urgently needed within NASA that will give specific concern to determining the current status of EMC standards and specifications and that will evaluate their influence, application and management on the effective use of the frequency spectrum.

A common expression of concern heard often in the EMC engineering community is that existing EMC/RFI standards and specifications are "out of date", "poorly enforced", "too general", etc. If these concerns are justified, what should be done, who should do it, and what are the positive benefits as well as the costs of implementing a new breed of special tailored aerospace equipment standards?

This section of the report does not include any specific recommendations for improvements to existing standards or specifications. It does, however, describe an effort that NASA should undertake that can provide the basis for recommendations designed to improve the standards themselves, the methods by which they should be applied, updated and managed. Specifically, the effort to be described calls for, (1) an exhaustive survey and collection of NASA applied standards and specifications leading to a summary of pertinent data, and a determination of the measurable equipment performance parameters and the measurement techniques by which these values are obtained, (2) an identification of NASA electronic equipments which are presently exempt from the requirements outlined in existing performance standards together with the known or suspected reasons for these exclusions, (3) a determination of the NASA procedures governing the development, application and enforcement of standards, the cognizant offices within NASA and their respective roles during the system design, equipment development, manufacturing, deployment and operational life cycles of NASA aerospace electronic systems, and (4) a study to determine the extent to which improved standards, standards management and procedures may contribute in some measure to the more effective use of NASA allocated portions of the frequency spectrum.

3.7.1.1 Performance Standards and Specifications and Their Application

A SURVEY AND A SUMMARY

A comprehensive survey of the EMC/RFI standards and specifications currently being applied by the NASA field centers as well as a search of military, other government agency and professional advisory society standards should be the initial step.

Together with the data gathering process, a determination should also be made of the measurement methods presently used to demonstrate compliance with these standards. This should include a qualitative description of the tests, their applicable ranges and limits, equipment classes subject to tests apply.

It is imperative that the data extracted from the various standards permit (1) a general comparison between standards, (2) identification of deficiencies or voids in these standards, (3) point to classes of aerospace equipments for which existing standards appear to be adequate and to those for which the standards are not complete, restrictive enough or not well administered, (4) identify those portions of the frequency spectrum that appear to be well supervised by standards as well as those portions that are not, (5) point to wide differences in equipment performance limits between standards and thus indirectly between using agencies or centers.

3.7.1.2 Aerospace Equipments Not Subject to Standards

WHAT ARE THEY AND WHY NO STANDARDS?

Interference generated by ignition system, motor-generator sets and other nonintended radiators and the susceptibility levels of such equipments as aerospace computers are not adequately provided for in existing standards.

A large group of equipments are subject to only minimal standardization, control or regulation. Equipments in this category include, (1) equipments allocated or assigned to sparsely occupied, closely controlled or noncritical portions of the spectrum, (2) very low power devices, (3) restricted and incidental radiation devices, (4) the entire range of nontelecommunications electrical equipment capable of producing noise and interference, (5) equipments employing new transmission, reception or antenna techniques for which there presently does not exist an appropriate performance standard, (6) equipments exempted to some extent from standards for economic reasons (e.g., commercial radio and television receivers).

An effort should be made to categorize the various types of equipments having limited standards or regulations, establish the rationale for these exemptions from or relaxation of standards, and identify those systems which require additional standards and the reasons for these additional requirements.

3.7.1.3 Organizations and Procedures Governing Standards

DEVELOPMENT, ENFORCEMENT AND UPDATING OF STANDARDS

Perhaps the most critical factor relating equipment performance standards and spectrum utilization is consideration of the structure of the organizations responsible for the development, enforcement, and updating of these standards.

Before a judgment can be made effecting possible structual changes in or additions to these organizations and their operational methods, it is essential to understand clearly the present organizational structures. Pertinent to this observation, it is recommended that problem areas should be identified through the examination of:

(1) Organizations or offices without and within NASA involved in the standards process,

(2) The interrelationships among these offices, the responsibilities held in common, and possible voids in responsibility,

(3) The degree to which standards are enforced and effectiveness of penalities for standards abuse,

(4) The standards revision and updating procedures, and

(5) The stages of equipment development and implementation at which standards become applicable.

3.7.1.4 Economic Versus Frequency Utilization Trade-Offs in Standardization

THE DECISION TO STRENGTHEN STANDARDS

It is clear that some cost/benefit relationship must ultimately be the decisive factor in the strengthening of equipment performance standards.

In order to be able to specify what combination and weighting of factors such as advances in aerospace telecommunications technology and equipment standards, intensification of frequency sharing or the exploitation of new regions of the spectrum should be applied to the problem of spectrum utilization, it is important to develop criteria for distinguishing more efficient spectrum use configurations from less efficient ones. Utilizing acceptable criteria, it is recommended that a study be performed to determine the cost/standard improvement balance resulting in improved use of the spectrum by NASA. Some of the more obvious costs in strengthening standards are, (1) the cost of engineering research designed to improve aerospace equipment characteristics, (2) the cost of streamlining the operating procedures of the NASA regulatory agencies, and (3) the cost of improved equipment via new design or modifications to existing equipment. The benefits to be derived from a standards improvement program include (1) increased spectrum occupancy, (2) improved equipment performance due to possible reduction of interference, (3) possible extension of the usuable spectrum, and (4) more efficient administration of standards policies.

In summary, the effort discussed would provide NASA with a clear delineation of the technical shortcomings in the present standards process and the methods by which these deficiencies could be resolved. It would also point to methods by which standards should be developed, applied updated and regulated and the procedures for integrating the recommended standards process into the broader realm of frequency management.

3.7.2 EMC/Frequency Management Information Dissemination Via a Series of Handbooks

WHY THE NEED FOR HANDBOOKS?

There does not exist today a reasonably applicable, up-to-date, and comprehensive compilation of information on the subject of EMC/EMI/Frequency Management that even in the loose sense could be termed a handbook.

Ten years ago, there was a great need for educating the engineering community to the necessity for promoting electromagnetic compatibility. Although the job is not complete, convincing people that EMC belongs as an equal partner with systems analysis, reliability and cost effectiveness is no longer the key problem. Rather, it is in providing the right kind of EMC information, in a usable format, to the people in a position to do something about EMC. Often, a frequency planner, program manager, system or circuit designer, desiring to do something about EMC, finds that much of the needed information either does not exist or must be painstakingly culled from a mountain of voluminous reports. Many of these reports do not directly pertain to his problem and when techniques are found that may be applicable to his situation, he often has difficulty in judging the extent to which they apply. In all too many cases, a user will initiate his own research, unnecessarily duplicating the work of others, rather then spend time searching. Then, adding insult to injury, his results are no better documented than others.

There exists to date only a single reasonably successful and valiant vanguard attempt to produce an EMC handbook. This handbook, RADC-TR-66-1, "Interference Notebook" was produced by contract personnel for the Rome Air Development Center under their Project 4540. No critique of this valuable work will be undertaken here. However, its direct applicability to aerospace EMC problems is questionable, since the contents are essentially a compilation of RADC's EMC work in ground electronic systems. The notebook was prepared in 1966, and the studies from which the bulk of the contents were extracted were completed in large part between 1959 to 1965, thus the notebook is hardly up-to-date in regard to modern aerospace communication systems. By intent, it treated the EMC subject of "Prediction and Analysis", discussing transmitter, receiver, and antenna systems, propagation, interference suppression and control techniques and the effect of components and techniques on interference vulnerability. It did not touch on the subjects of EMC/EMI measurements, frequency allocation or assignment or design guidance to reduce EMI and thus could not be termed comprehensive in any sense. What this all amounts to, is that there is a great requirement and an equally great void in regard to handbooks for use by frequency planners, program managers, system and circuit designers and any other groups of persons interested in doing something about aerospace EMC problems.

3.7.2.1 A Brief Outline of NASA Aerospace EMC Handbook Requirements

WHAT KIND OF HANDBOOKS?

A new breed of handbooks are sorely needed that emphasize procedures, instructions, methods of EMI problem prediction and their solution and that de-emphasize the simple cataloging of raw information with little or no guidance as to its use.

Handbooks are a form of compact, nonautomated information retrieval systems. They can be of a tutorial nature or can be designed to answer specific questions, in this case relating to EMC. The subject of these handbooks, EMC, is an applied science and as such is made up of many disciplines, including communication, information, antenna and propagation theory to mention but a few. Any EMC handbook that attempts to include a survey or summary of these sciences in a quixotic attempt to be "comprehensive" or "complete" is bound to either end as multivolume series or as a dismal failure. Also of little value are those handbooks that discuss each element of EMC (e.g., receivers, antennas, propagation, frequency allocation) separately making little attempt, for example, to instruct the user which of many models (e.g., propagation path loss) is applicable to his problem, or how each of the element models might be combined to arrive at a desired result.

Handbooks must be prepared for a relatively narrow audience. Thus, a handbook prepared for high level frequency planners would not suffice for circuit designers whose goal at the moment may be EMI reduction and vice versa. Handbooks cannot answer all questions but should be written expressly in response to those questions which are presently being asked and those that the forward looking handbook writer can foresee. Thus, for example, a NASA aerospace EMC handbook should contain complete answers to the questions, "What are the electromagnetic compatibility implications of flying a VHF-UHF communication experiment in a polar nonsynchronous orbit?", or "Is it possible to package a 3 GHz scatterometer and a 9 GHz interferometer on the NIMBUS-G satellite?". Certainly a handbook cannot foresee the precise questions it will be asked, but it must contain generic solutions within whose range of problem solution techniques and answers lie the desired solution to the particular question posed.

It is recommended that NASA develop a series of EMC/EMI/Frequency Management handbooks. The subject matter for these handbooks should be:

1. EMC and the Aerospace Circuit Designer
2. NASA Frequency Planning and Management
3. Aerospace EMC Systems Analysis Within NASA

The first of these as the title infers would be prepared for those circuit designers within NASA and as a guide, perhaps later to become a standard for NASA contractors. The handbook should contain a description of the EMI phenomena (e.g., spurious responses, desensitization, intermodulation, etc.) that can occur in the electronic circuits and components used in NASA aerospace equipments. It should also provide the design engineer with the mathematical routines that will enable him to evaluate the EMI potential of any circuit or component in use or proposed. Finally, a most important purpose of the handbook should be to provide the design engineer with quantitative guidance for the optimum selection of available circuit types or configurations and components to perform a particular electronic function.

The second handbook, prepared for NASA frequency managers and planners at all levels, should contain the policies and procedures for management of NASA allocated portions of the frequency spectrum, the interrelationships existing between NASA frequency managers, the IRAC and other regulatory agencies, procedures for requesting frequency allocations and making frequency assignments, frequency coordination procedures, procedures for establishing, updating and managing a spectrum usage reporting system, a summary of present and planned NASA spectrum requirements, a description of the present allowable emissions, bandwidths and frequency tolerances on a per frequency basis, and instructions pertaining to the reporting, identification and elimination of radio frequency interference.

The handbook, "Aerospace EMC Systems Analysis Within NASA", should be developed for those persons within NASA tasked with predicting the interference potential of aerospace equipments during the concept definition phase of a systems development prior to hardware design and certainly before a frequency allocation and assignment is made to the equipment. It should include techniques for siting new aerospace ground stations, determining the frequency/distance coordination required between satellites and terrestrial equipments sharing the same frequency bands, techniques for predicting and minimizing interference onboard satellites and aircraft, and procedures for analyzing the effects of interference in other generic type problem situations.

3.7.3 A NASA Frequency Management Program

THE DEVELOPMENT OF NEEDED AEROSPACE EMC TOOLS WILL ENHANCE THE FREQUENCY MANAGEMENT CAPABILITY OF NASA

A staff of EMC engineers at a high level within NASA could provide a frequency management program responsive to current problems and capable of projecting and providing for frequency requirements throughout NASA in the 1970's.

A handbook for NASA frequency managers and planners at all levels was described in the previous section. A staff of EMC engineers at a high level within NASA, possibly within the Office of Communications and Frequency Management, NASA Headquarters should be established and should take the responsibility for setting into motion the procedures for establishing, updating and managing a spectrum usage reporting system as well as developing a file of the characteristics for present and planned NASA RF experiments.

The spectrum requirements for the planned and proposed earth orbiting experiments for the 1970's are available from various sources scattered throughout NASA and from investigators working at various universities or in private industry. In order to accomplish the best possible frequency management planning for NASA and to allow an adequately early consideration of other users of the frequency spectrum, it is imperative that all of the spectrum usage information be made readily accessible to the NASA frequency coordinators. The first task to be accomplished by the staff of EMC engineers would be the collection of data for all of the known experiments so that a nominal characteristics file of the various equipments, by frequency band could be assembled for ready access. The equipments for which nominal characteristics should be collected should include passive devices such as interferometers, active devices, such as scatterometers, as well as communication and telemetry devices.

Once the nominal characteristics data file has been assembled, other existing data bases should be interrogated to determine the nature, location and quantity of emitters and receivers operating on or adjacent to the NASA assigned frequencies. With this information, possibly sorted by frequency band, NASA center or any other convenient grouping, the necessary decisions and recommendations for efficient and pratical spectrum utilization can be made at an early and effective date.

The file described above could be kept current by implementing a NASA-wide reporting system which would automatically tag new frequency requirements at a very early date, and certainly long before hardware is procurred. Initial data could be obtained from sources such as the NASA Research and Technology Resume forms (NASA Form 1122) at the same time that funding is being requested for an experimental study. The objective of any NASA spectrum usage file and reporting system would be to place the NASA frequency manager in the main stream of planned frequency usage while at the same time making this information available to other interested users throughout NASA.

Specific spectrum utilization problems requiring additional data and study could be analyzed by the EMC staff at NASA Headquarters for any NASA field center. Complete analyses of the compatibility aspects, including the parameters of modulation type, desired signal-to-noise ratio and possible intefering signal-to-noise ratio for any EMC problem could be handled by such a group. A frequency management analysis service such as the one described would be invaluable for such applications as outlining, presenting and defending future NASA frequency requirements in preparation for such international gatherings as the International Telecommunic-tions Union Conference to be held in late 1970, as well as for any similar frequency coordination assemblies between frequency allocation groups within the United States.

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